Composing with Matter

Interdisciplinary Explorations Between the Natural and the Artificial

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<u>Declaration</u>

I hereby declare that the work in this dissertation and the work presented in the accompanying portfolio have been carried out by myself except as otherwise specified.

Signed,

Mari Ohno

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Abstract

This practice-based research, which includes a written thesis and a portfolio of creative practice, represents the interdisciplinary exploration of co-composition between natural and artificial matter as otherworldly phenomena. Accelerated by the application of recent technologies to control natural materials, matter has become merged between nature and artefacts, offering new potentials, where the boundaries are becoming increasingly blurred. This thesis presents a series of complementing sound art works, including *transition [systemic]*, *transition [characteristic]*, and *moment*, which were devised through co-composing towards a creative outcome that combines sonic and visual elements by integrating natural and artificial matter as co-authors and co-makers within the creative process to generate multiple perspectives. Raising questions of the boundary between nature and artificiality, it aims to consider a new methodology for sound art in the human-dominated, Anthropocene epoch.

This research employs natural elements and processes to engage with sonic and visual anthropomorphism. It is focused on generative processes in the organisation of matter, here analysed and harnessed for sound expression, using acoustic phenomena including the inaudible range that can be perceived through matter. Through a laboratory-based study made in collaboration with scientists, three ‘life-like’ features of the generative processes of materials are discussed: 1) fusion and division, 2) network formation, and 3) pulse and rhythm. The practice explores these features to develop a new methodology of authorship and making, examining the following two questions. How can life-like behaviours of matter be portrayed through sonic and visual modes of expression? And in what ways might the expression of life-like behaviours be grasped by human perception? In conclusion, by

integrating the agency of matter into the compositional processes, life-like features – as described by current theories in art, design, science, and philosophy – are made apparent.

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1. Introduction

Practice Prior to PhD Research

My practice in this PhD research aims to investigate natural elements and processes, focusing on the boundary between the natural and the artificial, and compose them so as to express them through the medium of sound. According to the *Oxford English Dictionary*, ‘nature’ refers to ‘[t]he phenomena of the physical world collectively; esp. plants, animals, and other features and products of the earth itself, as opposed to humans and human creations’ or ‘[i]n wider sense: the whole natural world, including human beings’ (OED Online 2019c). This general definition of ‘nature’ is considered from the anthropocentric viewpoint. Yet it is becoming increasingly difficult to clearly separate the boundary between the natural and artificial in matter, as recent technologies enable the control of natural materials for new potentials. In a study of environmental philosophy and theory, Timothy Morton asserts that nature is not opposed to humans and human creations. In his words, ‘[s]trange as it may sound, the idea of nature is getting in the way of properly ecological forms of culture, philosophy, politics, and art’ (Morton 2007, 1). Morton reframes the idea of nature as follows:

> ‘nature’ occupies at least three places in symbolic language. First, it is a mere empty placeholder for a host of other concepts. Second, it has the force of law, a norm against which deviation is measured. Third, ‘nature’ is a Pandora’s box, a word that encapsulates a potentially infinite series of disparate fantasy objects. (Morton 2007, 14)

In his ecological considerations, Morton introduces the important concept of ‘mesh’ to refer to the interconnectedness of all living and non-living entities in our world across infinite and infinitesimal scales.

> The mesh consists of infinite connections and infinitesimal differences. Few would argue that a single evolutionary change isn’t minute. Scale is infinite in both directions: infinite in size and infinite in detail. And each being in the mesh interacts with others. The mesh isn’t static. We can’t rigidly specify anything as irrelevant. If there is no background and therefore no foreground, then where are we? We orient ourselves according to backgrounds against which we stand out. There is a word for a state without a foreground-background distinction: madness. (Morton 2010, 30)

Through a new lens of mesh, Morton argues for the boundary between the living and non-living in matter as follows:

> The ecological thought does, indeed, consist in the ramifications of the ‘truly wonderful fact’ of the mesh. All life forms are the mesh, and so are all the dead ones, as are their habitats, which are also made up of living and nonliving beings. We know even more now about how life forms have shaped Earth (think of oil, of oxygen – the first climate change cataclysm). We drive around using crushed dinosaur parts. Iron is mostly a by-product of bacterial metabolism. So is oxygen. Mountains can be made of shells and fossilized bacteria. Death and the mesh go together in another sense, too, because natural selection implies extinction. (Morton 2010, 29)

Through my practical experiments and theoretical research, I created sound art works that have temporal and spatial aspects, by ‘co-composing’ between natural and artificial materials through their interconnected relations, cooperation, and interaction. Developing this thesis, I use the term ‘co-

composition' to refer to the creation of sonic and visual modes of expression through the compositional process by collaborating with materials – which indicates that the author sets/facilitates a frame that leaves a blank space in which materials can behave freely and incorporates the unpredictable reactions produced by the materials themselves as 'co-author' and 'co-maker' in the process of composition. The definitions of 'co-authorship' and 'co-making' refer to the decision making and/or behaviour made by matter through the compositional processes in my anthropomorphic[1] practice. As this thesis will demonstrate, my materials are not limited to those within the conventional frameworks of identifying and selecting materials in sound art, but extend also to more interdisciplinary perspectives in art, design, science, and philosophy.

My anthropomorphic exploration is oriented in search of answers to a fundamental question of 'what is the boundary between natural and artificial matter?'. I hypothesise that the 'vitalism'[2] of matter – whether natural or artificial – can emerge through its decision making and/or behaviour. Therefore, in this thesis, my practice is focused on 'life-like' behaviours of matter grasped by human perception, which are found in the generative processes in the organisation of matter. My own use of the term 'life-like' refers to the biological properties of life in the systemic organisation of matter, which can be observed in either biologically living or non-living matter. This concept is inspired by the concept of 'autopoiesis' proposed by the Chilean biologists Humberto R. Maturana and Francisco J. Varela, which I discuss later in this chapter (Maturana and Varela 1980, originally published in 1973).[3] By

[1] A description of 'anthropomorphism' is discussed on pp.19–20 in this chapter.

[2] My own use of the term 'vitalism' is discussed on pp.20–22 in this chapter.

[3] A description of 'autopoiesis' is discussed on pp.22–23 in this chapter.

giving matter 'agency'[4] in the compositional processes, new creativity can be shaped with it through creation as co-author and production as co-maker. This doctoral research aims to explore, refine, and expand these life-like behaviours through the generative processes of materials, and to develop my methodology for harnessing sonic experiences co-composed by both natural and artificial matter through their constant 'conversations'.

This exploration emerged during my studies in Creativity in Music and Sound on my first master's course at Tokyo University of the Arts (2011–2014). My initial interest was in the thresholds of human perception and the biological reactions of a human body experiencing imperceptible acoustic phenomena beyond the human audible range (i.e. below and above 20 Hz to 20 kHz). I began by exploring various dimensions of human perception and the characteristics of sound, such as in sound installation and electroacoustic composition. To adequately explore this, I created sound art works using the inaudible sounds which exist in our lives and the acoustic environment as materials.

A crucial work during this developmental period was *bio effector*[5] (2012),[6] made during my MA study in Tokyo. This sound installation reveals the complexity, diversity, and vibrancy of sound in our internal bodies and highlights our inability to hear it despite its immediate proximity. The installation is comprised of a large sonic space which is affected by the surrounding environment. A membrane is

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[4] A description of 'agency' of matter is discussed on pp.21–22 in this chapter.

[5] I intentionally use lowercase for the title of the pieces in my practice.

[6] Mari Ohno and Kosuke Nagata *bio effector* (2012), sound installation, exhibited at 'Tokyo Art Meeting (III): Art & Music – Search for New Synesthesia', The Museum of Contemporary Art Tokyo, Japan, 18 Dec 2012 – 3 Feb 2013.

suspended in the gallery. The sound of visitors' bloodstreams is measured in real-time and the membrane vibrates like a drum in response. The composition's texture is created by controlling the membrane's vibration by changing its tension. The piece demonstrates an instrumental space that coexists with the environment, different to conventional musical instruments such as strings or membranophones. This is an attempt to express the inverted space of our internal bodies. The visitor can experience the body's internal sound from outside by entering the specific space of this piece.

Figure 1 *bio effector*, Mari Ohno and Kosuke Nagata (2012). Photo: Ryohei Tomita.

Another important work at this stage was *acoustic cluster* (2013).[7] This piece seeks to investigate something we are largely unaware of in our daily lives through the use of acoustic response. Sounds travel through the air as sound waves: invisible air shapes. In the installation environment, the piece

[7] Mari Ohno *acoustic cluster* (2013), sound installation, exhibited at 'Tokyo Experimental Festival vol.8', Tokyo Wonder Site Hongo, Japan, 26 Oct – 17 Nov 2013. (The organisation was re-named 'Tokyo Arts and Space' in October 2017.)

is comprised of a number of pipes of different lengths, each containing a microphone, and a speaker assembly generating random movement beneath the pipes. The distance between the speaker and microphones is expressed as microphone feedback. The pitch of the feedback response varies with the spatial properties of each pipe. *acoustic cluster* seeks to make audible the normally inaudible material of space. The piece employs natural space as an acoustic material representing invisible physical presence in our environment and makes it possible to experience a series of musical works through the transformation of spatial properties.

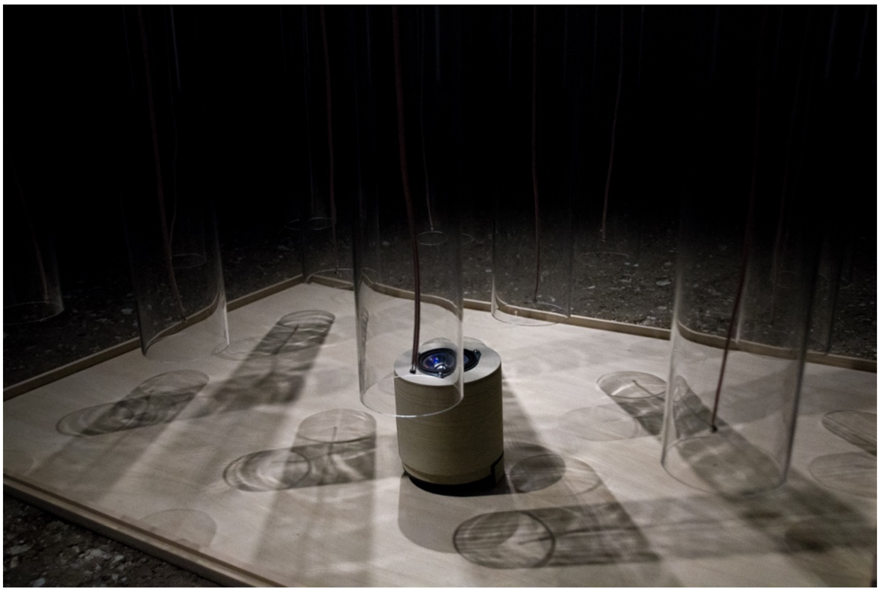

Figure 2 *acoustic cluster*, Mari Ohno (2013). Photo: Mari Ohno.

These two pieces were not initially aimed towards my current interest in the life-like features of material processes. In hindsight, however, they can be reinterpreted as pertaining to co-composition with biological and environmental materials. Such an interpretation coincides with my current interest as outlined in this thesis.

After my studies in Tokyo, I continued to research alternative ways for creating sound art works in conjunction with both the autonomous reactions of various materials and the artist's intention, for my second master's in Computational Arts at Goldsmiths, University of London (2014–2015). In addition to my initial interest in human perception and the biological reactions of a human body, my interest in my second MA study expanded to the autonomous reactions of non-human materials. During my studies in London, I created sound installations collaborating with biological or chemical reactions, that were autonomously driven by materials in an attempt to explore their expressive capabilities. I aimed to improve sound expression by incorporating the autonomous reactions of natural materials and phenomena into the creative outcome via computational methods. In my study, I specifically developed two approaches to sonic and visual expression that connect electronic components and computational systems with the autonomous reactions of materials.

1. Materials independently react to generate part of the creative outcome within the piece, along with the artist.
2. The outcome of the expression can be changed by the autonomous reaction of materials, independently from the artist's intention.

In these two approaches, the output was created by accepting the autonomous reactions in nature, whether or not they were intended by the artist. This resulted in a series of art works created through biological, chemical, and computational processes that brought the audience to recognise signs of life in created outcomes, in a way that conventional computing is unable to achieve.

In my previous works, I treated sound as an inaudible phenomenon through which to explore various dimensions of human perception. This imperceptible phenomenon was made audible through transformation into some other perceptible form, such as visible vibration, microphone feedback, or computation. These pieces revealed the unpredictable interaction between human and non-human elements in a natural environment, which I positively incorporated within the sound art works as a part of their expression. Thus, these sound pieces can be reinterpreted as co-compositions between human and non-human elements through the interactions.

For my next steps, I was interested in how natural and artificial matter could co-compose a sound art work, and how the result would influence the conscious experience of our bodies and minds. In this practice-based PhD research, I explore the life-like behaviours of matter to raise questions concerning the ambiguous boundary between the natural and the artificial. I thought there might be some recognisable characteristics to matter that is perceived to be living, and how such a matter is organised. Thus, I focused on the generative processes in the systemic organisation of matter to explore some of its life-like behaviours, and to consider what kinds of co-composition between natural and artificial matter would be possible through their autonomous and continuous interaction. In my practice in this research, I began by considering what are the biological properties of life and explored how natural and artificial matter may be integrated into a creative outcome with sonic and visual elements in organic and lively ways. Finally, I harnessed these behaviours towards sonic expression in three interdisciplinary projects, which were created through the co-composition between natural and artificial matter.

Methods

The relationship between natural and artificial matter is increasingly driven by technologies that enable us to create, manipulate, modify, and maintain 'living' materials. For instance, human beings use technologies that enhance and extend our bodies, such as microchip implants and electronic skin. In turn, artificial life is acquiring more human-like qualities with systemic functions such as machine learning and artificial psychology. The boundary between natural and artificial material is becoming blurred. These trends may be situated in the following two opposing approaches: 1) nature is developed in artificial ways, and 2) created artefacts are developed in natural ways. These approaches are not singular, but a continuously evolving complex conversation, each side having its own properties and sustainabilities. Both approaches reflect a tendency in current applied studies in science and engineering, including smart materials[8] and unconventional computing,[9] to create seamless experiences between the natural and the artificial. In art, they are also widely explored in many artistic forms, including 'moistmedia' (Ascott 2000)[10] and 'bio art' (Kac 2007).[11] The question of 'what is natural/artificial' is significant to consider in an alternative methodology for my practice.

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[8] See pp.55–56 in Chapter 2-2 for a description of 'smart materials'.

[9] See p.81 in Chapter 3-1 for a discussion of one approach to 'unconventional computing'.

[10] See p.42 in Chapter 2-1 for a description of 'moistmedia'.

[11] See pp.42–43 in Chapter 2-1 for a description of 'bio art'.

One of the major background themes behind this tendency to the blurred relationship between natural and artificial matter may be described by a geological view of the earth. The 'Anthropocene'[12] is a new geological epoch – a human-dominated world – proposed by Paul J. Crutzen and Eugene F. Stoermer (Crutzen and Stoermer 2000; Crutzen 2002; Crutzen 2006). Although this new geological epoch suggests that human beings have taken dominion over nature, human ability to control nature is still limited and its actual influence is not entirely controlled. The current natural environment could be said to be 'artificial nature' – impacts on nature are triggered by artificial activities, and the overall appearance is naturally reshaped into something different from the original. Conversely, it may be possible to create 'natural artefacts' that are made by human activities as a trigger and that continue to turn towards a natural course. Thus, one worthwhile way to create artefacts in this new epoch could be to connect them with nature, not separate them from it, with nature serving as a co-author in the creation and as a co-maker in the production. In Chapter 2-1 *Matter in the Anthropocene*, I discuss in more detail the concept of the Anthropocene and relevant discourses, for example, the philosophical concepts of 'vibrant matter' (Bennett 2010),[13] 'hyperobjects' (Morton 2010; Morton 2013),[14] and others.

This 'post-anthropocentric' mode of thought involves the development of an alternative methodology of authorship and making for my sound art works, through discussion of the boundary between natural and artificial matter. According to the *Oxford English Dictionary*, 'anthropocentric' is defined as:

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[12] See pp.29–30 in Chapter 2-1 for a description of the 'Anthropocene'.

[13] See pp.38–39 in Chapter 2-1 for a description of 'vibrant matter'.

[14] See pp.39–40 in Chapter 2-1 for a description of 'hyperobjects'.

‘centring on humanity or human beings; regarding humanity as the central or most important element of existence, esp. as opposed to God or the natural world’ (OED Online 2019a). For the purpose of this thesis, the term ‘post-anthropocentric’ refers to the integrated relationship between the human and natural worlds, not centring on one or the other of them. Within this post-anthropocentric mind, sound could be said to be ‘matter’[15] too. According to the definition of matter in classical science, sound is not actually matter. However, everything is composed of matter, which is changing all the time under a microscopic gaze. In my interpretation, sound may be said to be an invisible and impermanent phenomenon: a waveform of energy that transmits vibrations through matter. In other words, sound can be perceived through the vibrations of ‘matter’, not only via its physical characteristics, but also via the temporal and spatial attributes of its reception. The elements of time and space are common for all matter and are essential for looking into the process of the change of matter on the immense scales beyond human perception from the infinitesimal to the infinite. Thus, time and space are the perceived ‘materiality’ of acoustic phenomena, and their characteristics can be shaped through the constant conversations between human and materials. In Chapter 2-2 *Matter of Sound*, I explore the interdisciplinary perspectives of matter, including the definition of matter and sound and the materiality of sound in science, design, and art.

This thesis engages with sonic and visual anthropomorphism[16] within the process of co-composition between natural and artificial matter. As a premise of anthropomorphisation, psychologically, humans

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[15] See pp.45–46 in Chapter 2-2 for a discussion of my own use of the term ‘matter’.

[16] According to the *Oxford English Dictionary*, the term ‘anthropomorphism’ means ‘the attribution of human personality or characteristics to something non-human, as an animal, object, etc.’ (OED Online 2019b).

have a cognitive function that tends to unconsciously recognise the essence of life when they see inorganic materials make meaningful movements, or shapes and patterns that feel characteristic of the human face and body.[17] In the process of co-composition through the integrated relationships between natural and artificial materials, there should be the autonomous reactions of the materials and autonomous interactions between materials. These can be interpreted as the intention for authorship and making of the creative outcome. Strictly speaking, all life-forms in nature are composed of chemical compounds, which are not living. However, whether matter is biologically living or non-living depends on a sense of vitalism in the organisation of matter, which can emerge from the decision making and/or behaviour of the materials.

This hypothesis relates to the concept of 'élan vital' (vital impulse) proposed by the French philosopher Henri Bergson (Bergson 1998). In Bergson's book *Creative Evolution*, originally published in 1907, he proposes that there should be substance-free life as well as non-living substance (inorganic matter). According to his theory, the substance-free life is even more fundamental life, which is materialised into life. He proposes the concept of 'élan vital', which is a vital force that is more creative instinct, and the evolution of life forms through biological variety and natural selection as motivated by this vital force. Bergson classifies two opposing metaphors of the term 'intellect' and 'instinct' in the evaluation process. The following excerpt describes his idea of the 'intellect':

> We see that the intellect, so skillful in dealing with the inert, is awkward the moment it touches the living. Whether it wants to treat the life of the body or the life of the mind, it proceeds

[17] More details are given in Stafford and Webb 2004, 258–264.

> with the rigor, the stiffness and the brutality of an instrument not designed for such use. … *The intellect is characterized by a natural inability to comprehend life*. (Bergson 1998, 165)

Even though the ‘intellect’ is a conscious process, ‘instinct’ is a more organic impulse:

> Instinct, on the contrary, is molded on the very form of life. While intelligence treats everything mechanically, instinct proceeds, so to speak, organically. If the consciousness that slumbers in it should awake, if it were wound up into knowledge instead of being wound off into action, if we could ask and it could reply, it would give up to us the most intimate secrets of life. (Bergson 1998, 165)

According to Bergson’s theory, the relationship between ‘intellect’ and ‘instinct’ is not intersective:

> [I]t is impossible for intelligence to re-absorb instinct. That which is instinctive in instinct cannot be expressed in terms of intelligence, nor, consequently, can it be analyzed. (Bergson 1998, 168)

The ‘agency’ of matter which can emerge from its decision making and/or behaviour can be conceived as the emergence of non-substance life; what I am referring to as ‘vitalism’. This anthropomorphic idea is analysed and harnessed for my practice. The sonic and visual expression of my practice is created by allowing ‘material and nonhuman agency’, as discussed by Carl Knappett and Lambros Malafouris (2008, ix). Knappett and Malafouris state that ‘when agency is linked strictly to consciousness and intentionality, we have very little scope for extending its reach beyond the human’ (Knappett and Malafouris 2008, ix). However, the ‘creativity’ coming through the agency of matter is autonomously extended, whether the artist intends it or not. It highlights the ‘order and disorder’ of non-human elements. In this thesis, I specify that the properties of ‘order’ consist of the predictable features which are linked to human consciousness and intentionality within a system, while those parts of the system from which such features are not evident is ‘disorder’. Knappett and Malafouris assert:

> This human-centred view of agents and artefacts is not limited to those artefacts we design to be like agents. It extends to a much wider and more prosaic world of artefacts and matter, an environment of things that is conceived on our own terms, under our control and designed to serve. (Knappett and Malafouris 2008, ix)

In a sense, it can be said that the output of the autonomous creation is actually created cooperatively by both humans and non-human materials. However, such an outcome will always be interpreted anthropocentrically: ‘it is common sense that agency should be conceived anthropocentrically – how can it be otherwise? We are centre-stage in our lives, not these artefacts, however mundane, or indeed intelligent’ (Knappett and Malafouris 2008, ix). There may be some recognisably life-like features in the generative processes of materials motivated by the agency of matter, regardless of the state of life. My practice in this PhD research is created through the mimicry of life-like behaviours through the organisation of matter.

In one approach to life-like behaviours in the organisation of matter, Maturana and Varela propose the concept of ‘autopoiesis’, which is a coined word combining ‘auto’ (self) and ‘poiesis’ (creation, production) in the Greek, to describe one of the advanced system theories for living cells and nervous systems characterised by autonomous processes. This term was originally introduced in their book *Autopoiesis and Cognition: The Realization of the Living* (1973). The theory is based on the two fundamental questions of ‘What is the organisation of the living?’ and ‘What takes place in the phenomenon of perception?' (Maturana and Varela 1980, xii). The definition of an autopoietic system is as follows:

> An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network. (Maturana and Varela 1980, 78–79)

The present thesis can be said to be an attempt to explore 'autopoietic' behaviours through the generative processes of materials. In Chapter 2-3 *Generative Processes of Matter*, I discuss scientific theories of the evolution of life represented by the British naturalist Charles Darwin and the Russian biochemist Aleksandr Oparin, and a recent research trend in artificial life called 'protocells',[18] with related projects in art and design.[19] In addition, I discuss new creative methodologies that combine materials and processes from nature, such as the concepts of 'biomimicry' (Benyus 2008)[20] and 'material ecology' (Oxman et al. 2015).[21]

Overall, the present thesis examines an alternative methodology for sound art which explores non-living systems made from genetic materials, raising questions of the boundary between natural and

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[18] See pp.62–65 in Chapter 2-3 for the concept and history of 'protocells'.

[19] See pp.65–67 in Chapter 2-3 for related projects of 'protocells' in art and design.

[20] See pp.67–68 in Chapter 2-3 for a description of 'biomimicry'.

[21] See p.68 in Chapter 2-3 for a description of 'material ecology'.

artificial matter in the Anthropocene. How do we re-define living matter in the Anthropocene? What gives matter the biological properties of life? These concerns are addressed in my theoretical approach and motivate the themes of my practice. My hypothesis is that both living and non-living matter exhibit life-like behaviours through the generative processes of materials, motivated by the agency of matter. In practice, this anthropomorphic idea is examined by investigating the following two questions: 'how can life-like behaviours of matter be portrayed through sonic and visual modes of expression?' and 'in what ways might the expression of life-like behaviours be grasped by human perception?'.

The methodology behind co-composition between natural and artificial matter is that of positively allowing the agency of matter into the compositional processes. Matter's agency runs through its 'lifetime', which is greatly expanded from a human-recognisable scale. Thus, we can interpret the integrated outcome of natural and artificial matter through co-composition by looking at the generative processes of materials which occur on immense scales of time and space, including extremes from the infinite to the infinitesimal that lie beyond human perception. While the scales of artificial matter are set within a perceptible range, those of natural matter lie beyond human perception from the infinite to the infinitesimal. This concept relates to vibrant matter (Bennett 2010) and hyperobjects (Morton 2010; Morton 2013). This method of co-composition brings about a creative outcome with sonic and visual elements, through a constant interconnected 'conversation' between natural and artificial matter as co-author and co-maker. This alternative methodology for sonic and visual expression would facilitate the interconnected relations, cooperation, and interaction between natural and artificial matter by applying current theories in art, design, science, and philosophy that are discussed in this thesis to a practice that may be experienced aesthetically.

In the early stages of this research, I experimented with tissue culture to consider life-like behaviours, through the observation of the growing process of living cells. I did this at the research laboratory at SymbioticA, the Centre of Excellence in Biological Arts at the University of Western Australia, as a resident artist in 2016. This residency was supported by Oron Catts, the director of SymbioticA, and Dr Ionat Zurr, who is an artist, researcher, and academic co-ordinator at SymbioticA. In this practical experiment, I cultured mouse myoblast cells called C2C12, to observe the complex mechanism of life; see Chapter 3-1 *Life-like Behaviours of Matter* for more details. Through this laboratory-based experiment, I found the following three life-like features of the distinctive generative processes: 1) fusion and division, 2) network formation, and 3) pulse and rhythm. All of my practice in this thesis consists of interdisciplinary explorations of these life-like behaviours. My pieces are discussed within Chapters 3-2 *Fusion and Division*, 3-3 *Network Formation*, and 3-4 *Pulse and Rhythm*, respectively.

In my practice, I explored these three features of life-like behaviours in non-living matter through the creation of three sound installations across two projects, and two related studies in the processes of the main projects. The pieces are created with an interdisciplinary perspective through laboratory-based experiments conducted in collaboration with scientists. The first project, *transition*, is designed to consider the time scale between the natural and the artificial. In *transition [systemic]*, I explored 'fusion and division' using chemical reactions to mimic the primitive life cycle of evolution, inspired by protocells. In *transition [characteristic]*, I examined 'network formation' using crystallisation that exhibits a similarity to the organic processes of structural development. The second project, *moment*, considers 'pulse and rhythm', inspired by human pulses whose beats continuously interact with daily routines as internal rhythms. As a part of the creative process of my pieces, each piece in both projects includes two experimental studies: *energy in motion* and *spectrum*. All the sound pieces are propositions for an appropriate methodology for accessing the unexplored potentials of matter through the co-composition in sound art. Figure 3 lists the main pieces and related studies exploring the three life-like behaviours.

life-like behaviours	fusion and division	network formation	pulse and rhythm
main pieces	*transition [systemic]*	*transition [characteristic]*	*moment*
related studies	*energy in motion*	*spectrum*	

Figure 3 The five sound art works in relation to the three life-like behaviours.

Outline of Chapters

This thesis is divided into two parts: *Research Context* and *Practice*. The first part, Chapter 2 *Research Context*, consists of four sub-chapters in which I discuss the methodology I employed in my own practice-based research, relating concepts and techniques – such as protocells – to the compositional processes in my PhD portfolio. The first sub-chapter, Chapter 2-1 *Matter in the Anthropocene*, discusses the scientific background of the Anthropocene, and relevant philosophical discourses about the ambiguous boundary between natural and artificial matter.

Chapter 2-2 *Matter of Sound* considers the materiality of sonic experiences, inspired by alternative approaches in modern design. In describing the methodology employed in my sound art works, it explores how sound expression could give the agency of matter within the compositional processes, crossing the interdisciplinary definition and classification of matter, acoustics, and design, as well as relevant recent innovations, including smart materials.

Chapter 2-3 *Generative Processes of Matter* discusses genetic algorithms found in recent research and projects in science, art, and design. Firstly, it briefly summarises the scientific history of the chemical evaluation of life. Subsequently, it focuses on the recent scientific research of protocells, and discusses relevant projects in art. Finally, it introduces some methodologies in art and design to create an integrated outcome with both natural and artificial elements, inspired by natural design and processes. This sub-chapter leads to the last sub-chapter, Chapter 2-4 *Summary*.

The second part, Chapter 3 *Practice*, focuses on my own practice of sound art works created during the PhD process, including the laboratory-based experiments made in collaboration with scientists. This chapter consists of four sub-chapters. Chapter 3-1 *Life-like Behaviours of Matter* discusses my laboratory-based experiments with tissue culture at SymbioticA, to observe the life-like features of generative processes through the biological experiments. In addition to the experiments, some relevant projects in art and science are discussed in order to consider human understandings of the intermediate state between living and non-living matter.

Finally, I discuss in detail the sound practice submitted in my portfolio, towards exploring the life-like behaviours that I found in the experiments with tissue culture, discussed in the previous sub-chapter. The following three sub-chapters 3-2 *Fusion and Division*, 3-3 *Network Formation*, and 3-4 *Pulse and Rhythm* each look at one of three life-like behaviours of materials. Each sub-chapter is structured in four sections: first a description of the piece, then its context, process, and evaluation.

2. Research Context

2-1. Matter in the Anthropocene

The Anthropocene, a geological term proposed by Crutzen and Stoermer, defines a new human-dominated epoch that has arisen due to the huge impact of human activities on the earth that followed the Industrial Revolution.

> Considering these and many other major and still growing impacts of human activities on earth and atmosphere, and at all, including global, scales, it seems to us more than appropriate to emphasize the central role of mankind in geology and ecology by proposing to use the term 'anthropocene' for the current geological epoch. (Crutzen and Stoermer 2000, 17)

Crutzen and Stoermer suggest that the earth may have entered this new geological epoch following the post-glacial geological epoch known as the Holocene (Crutzen and Stoermer 2000; Crutzen 2002; Crutzen 2006). The time period of the Holocene encompasses the last 11,000 years. This term was originally proposed by Charles Lyell in 1833 and was officially approved in 1885 at the International Geological Congress (Hancock and Skinner 2000). Although the Anthropocene is yet to become formally approved as an epoch by the International Commission on Stratigraphy (ICS) and the International Union of Geological Sciences (IUGS), it was recently agreed for the submission of a formal proposal to the ICS by 2021, by the Anthropocene Working Group (AWG) (Subramanian 2019).

According to the research by Crutzen and Stoermer, it is assumed that the Anthropocene may have already begun in the late eighteenth century. They see it beginning with the exponential global effects in the increase of greenhouse gases, which was simultaneous with the innovation of the steam engine by James Watt in 1784. As a basis for the onset of the subdivision in the Quaternary period, the proposition suggests how the earth has been changed over the past two centuries. Through human activities such as population growth, energy consumption, and economic growth, the earth has experienced a drastic change in its environment, and that change is noticeable enough to leave semi-permanent traces on the earth. Although there are various opinions among the experts, the formal beginning of the Anthropocene is considered to be around 1950, when nuclear tests caused the emission of radioactive materials around the world (Carrington 2016).

Before the term of the Anthropocene epoch became established, some anthropologists and scientists had already remarked that environmental change on the earth suggested the end of nature. In 1989, the American environmentalist Bill McKibben proclaimed that nature has been changed by human forces in his book *The End of Nature* (1990). This book addresses climate change and global warming from different aspects, when these topics were gaining attention as emerging environmental issues around thirty years ago. In McKibben's words:

> By changing the weather, we make every spot on earth man-made and artificial. We have deprived nature of its independence, and that is fatal to its meaning. Nature's independence *is* its meaning; without it there is nothing but us. (McKibben 1990, 58)

McKibben claims that climate change establishes that nature is not independent from humans, but it is now affected by human activities.

> If the waves crash up against the beach, eroding dunes and destroying homes, it is not the awesome power of Mother Nature. It is the awesome power of Mother Nature as altered by the awesome power of man, who has overpowered in a century the processes that have been slowly evolving and changing of their own accord since the earth was born. (McKibben 1990, 60)

More recently, the American environmental historian John Robert McNeill has pointed out the abundant geological evidence that clearly distinguishes the present era (i.e. from the 1950s on) from the Holocene – the so-called Great Acceleration. According to McNeill, the Great Acceleration is a term that refers to the explosive increase of human activity after the Second World War, essentially the rapid growth of population, energy consumption, and economic activity (McNeill and Engelke 2014). In the late twentieth century, human activity had a remarkable influence on the global environment, especially in increasing demand for natural resources and creating environmental pollution, including greenhouse gases, ozone holes in the stratosphere, the temperature of the land surface, the acidification of the ocean, and the reduction of marine resources and tropical forests.[22]

The extensive discussion of the Anthropocene in recent years has brought up questions of how human beings should face the recent and future environmental change on the earth: should we control either

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[22] A research group led by Will Steffen updated to illustrate the 24 graphs of what kind of socio-economic and earth system trends the Great Acceleration have caused, and how these trends have been drastically changed over the past 60 years, from 1750 to 2010 (Steffen et al. 2015, 84–87).

nature or human activities to make a balance between them? Or should we reconsider nature and humans from their roots and create new relationships between them with alternative methodologies? The concept of *multispecies ethnography* defined by S. Eben Kirksey and Stefan Helmreich is one alternative approach to reconsidering human activities in anthropology through the link to nonhuman species: not only animals and plants but also microbes and fungi, and cross-species intersections (Kirksey and Helmreich 2010). The American feminist biologist Donna Haraway has had a great influence on the philosophy of this research trend of multispecies ethnography. In Haraway's *Primate Visions: Gender, Race, and Nature in the World of Modern Science*, published in 1989, she describes how humans' cultural imagination has been gradually changed by the political structures of gender, race, and class from the historical standpoint of primatology (Haraway 2006). Her more recent exploration of humans through the unsteady notion of 'species', in contrast to anthropocentrism, indicates that the development of human history and culture is deeply embedded in their relationship with various species (Haraway 2008). Some anthropologists have created biocultural examples of multispecies ethnography with various species, as can be seen in not only Helmreich's book *Alien Ocean: Anthropological Voyages in Microbial Seas* (2009), but also *Insectopedia* by Hugh Raffles (2010), *The Mushroom at the End of the World* by Anna Tsing (2015), and others.

Additionally, there are other discourses by which to consider the alternative relationship between nature and culture. In the context of anthropocentrism, nonhuman species have been considered as either living entities in nature as wildlife or living entities as a part of culture in human life. The book *Nature, Culture and Gender* (1980), co-edited by Carol P. MacCormack and Marilyn Strathern, contains a series of essays that argue for the dominance of culture compared with nature, in conjunction with gender formations from the anthropological point of view. MacCormack discusses her distinctive notion of ‘nature’ and ‘culture’. As she states:

> The ‘natural’ is that which is innate in our primate heritage and the ‘cultural’ is that which is arbitrary and artificial. In our evolutionary history we have improved and constrained ourselves by creating our own artificial rule-bound order. (MacCormack 1980, 6)

However, in the Anthropocene, it can be said that the nature that confronts humans does not exist. In another of Haraway’s writings, *The Companion Species Manifesto: Dogs, People, and Significant Otherness*, she indicates the inseparable and interconnected relationship between nature and culture, what she calls ‘natureculture’ (Haraway 2003). Natureculture is an interwoven framework of nature and culture in an ecological relationship which is formed by both biophysical and social structures. Inspired by Haraway’s idea of natureculture, the American primatologist and biological anthropologist Agustín Fuentes has demonstrated an anthropological example of ‘mutual ecologies’. Fuentes insists that ‘[h]umans are animals and members of a global ecology’, which is a widely supported view in biology, philosophy, ecological anthropology, and environmental anthropology (Fuentes 2010, 600). Through his ethnographic fieldwork of mutual ecologies between local people, tourists, and macaques at the temple forest complex at Padangtegal (Ubud), in Bali, Indonesia, Fuentes argues for the essential role of multispecies actions and interactions in both structural ecology and social ecology, observing how humans and animals form integrated connections in these ecological fields. His emphasis on mutual ecologies challenges the borderless binaries between three conflicting notions:

> We need to reject domesticated versus wild, natural versus unnatural, and engagement versus detachment dichotomies in the study of human-alloprimate interfaces. (Fuentes 2010, 618)

In relation to such approaches that consider both human and nonhuman species within an ecological system structured by natural and cultural elements, Morton, known as an advocate of 'object-oriented ontology', has engaged the human cognition of nonhuman objects, with special attention to ecocriticism and ecological theory. Before introducing Morton's philosophy, I will briefly summarise the concept of object-oriented ontology (OOO). OOO is a philosophical movement opposed to anthropocentric scientism that suggests that nonhuman objects exist independently beyond human cognition, and unrelated to other human and nonhuman objects. The 'object' in this theory refers to various things, not only physical objects in our daily lives, but also conceptual objects in physics and mathematics, collective objects in sociology, and even non-existent objects in mythology. The term 'object-oriented philosophy' was coined by the American speculative philosopher Graham Harman, originally in his doctoral thesis *Tool-being: Elements in a Theory of Objects* (Harman 1999). The concept was revised in his subsequent book *Tool-Being: Heidegger and the Metaphysics of Objects* (Harman 2002). Harman attempts to construct an ontology as a comprehensive framework of human cognition that can be applied to all sorts of objects, which is a unified model dealing with the relationship between nonhuman objects and the human cognition of objects. In OOO, the relationship between objects is always asymmetric and one-directional; this is representative of the concepts he calls 'undermining' and 'overmining' (Harman 2011). The former is a way of thinking in which an object is composed of a collection of smaller elements, and the objects that seem self-standing are actually made up of more essential elements.

> [O]bjects are too specific to deserve the name of ultimate reality, and dream up some deeper indeterminate basis from which specific things arise. (Harman 2011, 10)

The latter, on the other hand, is a position by which to 'reduce them upward rather than downward' (Harman 2011, 10). This is a way to understand an object within its context in the placed relations. For example:

> Consider the widespread empiricist view that the supposed objects of experience are nothing but bundles of qualities. The word 'apple' is merely a collective nickname for a series of discrete qualities habitually linked together: red, sweet, cold, hard, solid, juicy. What exist are individual impressions, ultimately in the form of tiny pixels of experience, and the customary conjunction of these puncta leads us to weave them into larger units. (Harman 2011, 11)

Although the objects in both positions are understood by either reducing to elements, or reducing to relations, this mode of thought should be interchangeable, depending on circumstances. When an object is recognised in relation to another object, a third object separated from that relation should also be recognised, to determine the place of the original object. This third object is also understood through undermining and overmining. Thus, the roles of subject and object are duplicated and function interchangeably in a structure in which relations and elements are nested.

Inspired by this mode of thought, Morton's philosophical explorations of ecocriticism have been developed since 2007 and were first published in the book *Ecology without Nature: Rethinking Environmental Aesthetics* (Morton 2007). Morton's attempt in this book is to recreate a new concept of 'ecology' within modern environmentalism, by regarding nature as a 'surrounding medium', not an objective atmosphere or environment. The surrounding medium encourages the existence of various things that are not limited to humans. As he states:

> Ecological writing keeps insisting that we are 'embedded' in nature. Nature is a surrounding medium that sustains our being. Due to the properties of the rhetoric that evokes the idea of a surrounding medium, ecological writing can never properly establish that this is nature and thus provide a compelling and consistent aesthetic basis for the new worldview that is meant to change society. It is a small operation, like tipping over a domino. (Morton 2007, 4–5)

Morton's concept of ecology indicates the ambiguous independence of nature from human notion. While nature is a surrounding medium for humans, it cannot be explicitly distinguished from evocative thoughts and imaginations in the human mind. The surrounding medium can be drawn not as a fixed place, but as an unfixed ambience that contains things constantly vibrating with rhythm, whose sound deeply resonates with human emotions.

> The idea of the environment is more or less a way of considering groups and collectives – humans surrounded by nature, or in continuity with other beings such as animals and plants. It is about being-with. (Morton 2007, 17)

This thought relates to the proposition of 'dark ecology', which is discussed in detail in Morton's more recent book *Dark Ecology: For a Logic of Future Coexistence* (Morton 2016). Dark ecology takes an attitude of accepting nature to include humans as it opposes the fantasy of aesthetic nature rooted in the Romantic period. Morton's dark ecology establishes a deeper position from which to look thoroughly at the reality of the darkness of nature that humans have overlooked; neither to worship nature as a religious object, nor to retrofit it as an object ravaged by industrialisation. In this sense, his idea is based on 'deep ecology', which intends to reject human privileges by equating other life with that of humans.

> 'Ecology without nature' could mean 'ecology without a *concept* of the natural.' Thinking, when it becomes ideological, tends to fixate on concepts rather than doing what is 'natural' to thought, namely, dissolving whatever has taken form. Ecological thinking that was not fixated, that did not stop at a particular concretization of its object, would thus be 'without nature.' To do ecocritique, we must consider the aesthetic dimension, for the aesthetic has been posited as a nonconceptual realm, a place where our ideas about things drop away. (Morton 2007, 24)

The dichotomies that have been discussed above, including humans versus nonhuman species, and nature versus culture, are all discussed within the framework that humans have made, such as anthropological, social, political, and ecological structures. Although these philosophical thoughts attempt to reinterpret the complex and interconnected relationships between natural/artificial elements or living/non-living entities, the limitations of human perception and cognition mean that such relationships can only be considered within human frameworks. To this extent, these ideas cannot be completely separated from anthropocentric ways of thinking. Displacing or decentring the notions of human in theoretical discussions and art practice in the post-anthropocentric[23] context requires us to speak outside of our perceivable world somehow.

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[23] See pp.18–19 in Chapter 1 for a discussion of my own use of the term 'post-anthropocentric'.

The following concepts are some approaches to considering how humans refer to matter beyond our perception. These relate to the anthropomorphic[24] practice in my research that explores vitalism[25] and the creative force as an author and maker possessed by both natural/artificial and living/non-living matter. How do we re-define living matter in the Anthropocene? What gives matter the biological properties of life? In order to consider these questions in approaching my practice, it is necessary to turn to the philosophical concept of vital materiality, proposed by the American political theorist and philosopher Jane Bennett. Bennett argues for the ontological consideration of 'vital materialism', which is a distinctive framework of a subject and object and their relationships, with political and theoretical implications. In her book Vibrant Matter: A Political Ecology of Things, published in 2010, Bennett insists that everything, both human and nonhuman including inorganic matter, is composed of 'vibrant matter' which is alive in complex and interconnected relationships (Bennett 2010). According to her, nonhuman bodies and inorganic entities have active powers of vibrant life in every event, just as humans do, as opposed to the traditional dichotomy in Western philosophy that considers matter to be stable and lifeless as a passive object, while humans are an active subject. She calls this lively power 'thing-power'. In Bennett's view:

> By 'things' I mean the materialities usually figured as inanimate objects, passive utilities, occasional interruptions or background context – figured, that is, in ways that give all the active, creative power to humans. (Bennett quoted in Khan 2009, 92)

[24] See pp.19–20 in Chapter 1 for a description of 'anthropomorphism'.

[25] See pp.20–22 in Chapter 1 for a discussion of my own use of the term 'vitalism'.

> By ‘vitality’ I mean the capacity of things – edibles, commodities, storms – not only to impede or block the will and designs of humans but also to act as quasi agents or forces with trajectories, propensities, or tendencies of their own. (Bennett 2010, viii)

In this theory the vital bodies of various matters are continuously affecting and affected by other bodies in complex assemblages of an agency that acts depending on the interaction of bodies and forces. The assemblage of this interconnected swarm is simultaneously and frequently generated and vanished within a certain time and space that is not formed like a centralised organisation. Bennett introduces the notion of ‘distributive agency’ as follows:

> In the tradition that defines agency as *moral* capacity, such new effects are understood as having arisen in the wake of an advance plan or an intention, for agency ‘involves not mere motion, but willed or intended motion, where motion can only be willed or intended by a *subject*.’ A theory of distributive agency, in contrast, does not posit a subject as the root cause of an effect. There are instead always a swarm of vitalities at play. The task becomes to identify the contours of the swarm and the kind of relations that obtain between its bits. … This understanding of agency does not deny the existence of that thrust called intentionality, but it does see it as less definitive of outcomes. It loosens the connections between efficacy and the moral subject, bringing efficacy closer to the idea of the power to make a difference that calls for response. (Bennett 2010, 31–32)

If matter has some sort of organic behaviour as described above, it could be said that it is moving and changing through time and space in a certain manner. However, the notion of time and space is an ambiguous one and the understanding of these notions depends on what scales we focus on.

Morton proposes another approach to those objects that exceed human cognition in another book, *The Ecological Thought* (2010). Here, he introduces the concept of ‘hyperobjects’, to discuss nonhuman objects massively existing in time and space widely extended beyond the human scale, giving the examples of Styrofoam, plutonium, and global warming (Morton 2010). With this concept, Morton attempts to describe how nonhuman objects over human scales can be recognised as hyperobjects.

> The ecological thought is a virus that infects all other areas of thinking. (Yet viruses, and virulence, are shunned in environmental ideology.) This book argues that ecology isn't just about global warming, recycling, and solar power – and also not just to do with everyday relationships between humans and nonhumans. It has to do with love, loss, despair, and compassion. It has to do with depression and psychosis. It has to do with capitalism and with what might exist after capitalism. It has to do with amazement, open-mindedness, and wonder. It has to do with doubt, confusion, and skepticism. It has to do with concepts of space and time. It has to do with delight, beauty, ugliness, disgust, irony, and pain. It has to do with consciousness and awareness. It has to do with ideology and critique. It has to do with reading and writing. It has to do with race, class, and gender. It has to do with sexuality. It has to do with ideas of self and the weird paradoxes of subjectivity. It has to do with society. It has to do with coexistence. (Morton 2010, 2)

Following these publications, Morton elaborated on the concept of hyperobjects in another book *Hyperobjects: Philosophy and Ecology after the End of the World* (2013). In this book, he indicates the following five properties of hyperobjects: viscosity, nonlocality, temporal undulation, phasing, and interobjectivity (Morton 2013). To deepen our understanding, he gives an example of these properties in his essay for *High Country News*, published in 2015.

> We can see, for instance, that global warming has the properties of a hyperobject. It is 'viscous' – whatever I do, wherever I am, it sort of 'sticks' to me. It is 'nonlocal' – its effects are globally distributed through a huge tract of time. It forces me to experience time in an unusual way. It is 'phased' – I only experience pieces of it at any one time. And it is 'inter-objective' – it consists of all kinds of other entities but it isn't reducible to them. (Morton 2015)

Fundamentally, these philosophical concepts including OOO and nonhuman theory are discussed from an anthropocentric standpoint, as the human is the subject of a thinker. As long as human is the subject of thinking, the target of the thought other than human is present as an object; it is essentially difficult to think both the subject and the object from the same point of view, completely apart from anthropocentrism. In reality, the various boundaries derived from the interconnected relationship between nature and artefacts are made and understood within human perception and cognition. However, it is possible to at least understand that the unperceivable world exists by having an awareness that human has a quite limited perception of the whole world. Certainly, there should be unlimited scales that human cannot perceive. This thought relates to Bennett's idea of vibrant matter and Morton's concept of hyperobjects. To apply the complex and interconnected world of matter across unlimited scales into my methodology of co-composition in sound art, I use a new lens of sonic and visual anthropomorphism as the reflections of vibrant matter and hyperobjects. I reinterpreted acoustic phenomena as one of the elements within the interconnected relationships of matter across time and space. Thus, my sonic and visual exploration within the context of the Anthropocene begins by looking for ways in which the unperceivable can be 'sensed' with perceptible objects through some means.

Discussions about the collapse of the boundary between the natural and the artificial, and the living and the non-living in the Anthropocene have already been quite extensive in the international literature. As discussed above, they are dynamically linked to various sections of anthropology, primatology, ecology, sociology, and philosophy. The geological change that is the Anthropecene must give us alternative methodologies for art, design, and architecture as well. In this connection, some writers have proposed the methodological applications of the Anthropocene to our social life including art for the coexistence with all entities other than human, as discussed in the journal article *Geosocial Formations and the Anthropocene* by Nigel Clark and Kathryn Yusoff (2017), the book *Art in the Anthropocene: Encounters Among Aesthetics, Politics, Environments and Epistemologies* by Heather Davis and Etienne Turpin (2015), and the *Arts of Living on a Damaged Planet: Ghosts and Monsters of the Anthropocene* edited by Tsing, Heather Swanson, Elaine Gan, and Nils Bubandt (2017). In my practice, I engage with sonic and visual anthropomorphism through exploration of the boundary between the living and the non-living. It aims to bring out unexpected and surprising creative outcomes that humans cannot achieve by applying the collapse of this boundary to the processes of co-composition in sound art from a post-anthropocentric perspective. The creative force of matter occurs beyond our perception throughout the compositional processes, and it can be considered as a new form of vitalism in the Anthropocene.

Similarly, even outside the context of the Anthropocene, modern artists have also begun creative activities on the intermediate state between natural/artificial or living/non-living matter. For example, the British artist and cybernetician Roy Ascott proposed the concept of 'moistmedia' (Ascott 2000, 2). This is one alternative way of defining and interpreting the intermediate domain which is positioned between the wet media of biological living things in reality and the dry media of non-material things in virtuality. Furthermore, one of the historical pioneers in biological art, Eduardo Kac, created the name 'bio art' for his projects since 1997 that are related to biological materials (Kac 2007, 164). His projects suggest the historical and social meaning of creating new 'life' that lies behind the shift from digital technology to biotechnology. His main focus is to address the concepts of biological agency and biological objecthood, whose difference he describes as follows:

> The difference between biological agency and biological objecthood is that the first involves an active principle while the second implies material self-containment. (Kac 2007, 164)

In order to deal with unstable living materials in art, it should be necessary to positively accept the order and disorder[26] of nature, which is the biological agency and objecthood in artificial expression, not to combat them. This mode of thought has a link to the post-anthropocentric methodology explored in my practice in this PhD research; see Chapter 3 *Practice* for more details.

The collapse of the boundary between natural and artificial matter is rapidly evolving in actual human life today. As one approach to considering the vitalism of this intermediate state between natural and artificial matter, I adopt the methodology of co-composition in my practice, particularly focused on the generative processes in the organisation of matter. I hypothesise that the unperceivable creative force of matter can be sensed with perceptible objects, by analysing the life-like behaviours of matter made by its autonomous reactions and harnessing them into the compositional processes. Through an interconnected relationship between artist and materials as co-authors and co-makers in the processes of co-composition, the integrated creative outcome can be expanded with some unexpected and surprising elements. This outcome can be perceived, but it actually includes unperceivable elements. These unperceivable elements change the perceptible outcome under our perception within the

[26] See pp.21–22 in Chapter 1 for a discussion of my own use of the term ‘order and disorder’.

processes of co-composition. Thus, through the means of co-composition, the unperceivable creative force of matter motivated by its agency will be presented as perceptible elements.

2-2. Matter of Sound

Matter and Sound

According to the *Oxford English Dictionary*, the term ‘matter’ refers to ‘[t]he substance, or the substances collectively, of which something consists; constituent material, esp. of a particular kind’ (OED Online 2019g). However, this definition is considered within the context of anthropocentrism. In this human-dominated epoch, as discussed in the previous sub-chapter, is our definition of ‘matter’ sufficient? Everything that exists in the universe is made of matter, everything begins with matter, and matter is changing all the time. Thus, there should be an imperceptible world of matter too.

Before considering the definition of ‘matter’ in a new context for the Anthropocene, we need to review the definition in classical physics first. The definition of ‘matter’ in *The Dictionary of Physics* is as follows:

> In the global picture of classical physics, matter is a measurable and calculable quantity that is quite distinct from ▷*energy*, which is based on Newton’s distinction between the inertial and gravitational ▷*mass* of material bodies. In the ▷*special theory of relativity*, the concept of matter must be received through the recognition that light gas a finite velocity in ▷*electrodynamics*; in particular, mass and energy prove to be equivalent (▷*mass–energy equivalence*). The equivalence of inertial and gravitational mass (the ▷*equivalence principle*) becomes the foundation of the ▷*general theory of relativity*. (Dictionary of Physics 2004, 1416–1417)

Although the basic idea of matter was originally found in Aristotle's natural philosophy in the Ancient Greek, the definition in classical physics differs from those in philosophy and the other natural sciences.[27] In this thesis, my own use of the term 'matter' refers to a substance that exists in time and space, or an entity that is the source of various temporal and spatial phenomena. Matter comprises something and matter itself or its properties can be used as materials.[28]

In this context, it is considered that matter is a substance composed of atoms which consist of protons, electrons, and neutrons (DeMouthe 2006). Following this definition, matter can exist across different states – solid, liquid, and gas, also known as phases – depending on temperature and other conditions. This means that matter does not include particles of energy such as photons and waves such as sound and light. The properties of matter are defined by the chemical composition and internal structure of the substances, and physical and optical properties are essential for the identification of natural materials. Thus, matter is constantly changing beyond human perception and is unstable in its interactions with its environment, and it can be seen across two scales of time and space. All materials have multi-scale structures; the structure of materials can be observed differently depending on the scale of magnification.

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[27] According to the *Oxford English Dictionary*, the term 'matter' in Aristotelian and scholastic philosophy refers to 'component of a thing which has bare existence but requires an essential determinant (form) to make it a thing of a determinate kind' (OED Online 2019g).

[28] The definition of 'material' in the *Oxford English Dictionary* is as follows; '[t]he matter or substance from which a thing is or may be made' (OED Online 2019f).

Regarding the definition of sound in the physical sciences, sound is an acoustic phenomenon of a non-material kind, which is not exactly matter. Sound can be simplified as the waveforms of energy that transmit vibrations through matter and exist everywhere except in a vacuum where there are no air molecules for the vibration. It is mere wave vibrations and collisions of air molecules in a space, with an interaction with matter that causes absorption and reflection. Sound waves can be often analysed as sine waves with some characteristic properties, such as frequency, intensity, speed, and direction. Although the scientific definitions of matter focus on its visibility as a substance, in my interpretation, sound may be reinterpreted to be invisible and impermanent 'matter' that can be phenomenologically perceivable through the air in a space and through its interaction with matter as invisible air shapes.

Allan D. Pierce, widely known as one of the most important researchers in acoustics, proposes the following definition at the beginning of his book *Acoustics: An Introduction to Its Physical Principles and Applications* (1989, originally published in 1981):

> Acoustics is the science of sound, including its production, transmission, and effects. In present usage, the term *sound* implies not only phenomena in air responsible for the sensation of hearing but also whatever else is governed by analogous physical principles. (Pierce 1989, 1)

In Pierce's theory, acoustics is defined as mechanical wave motion, as opposed to the electromagnetic motion of optics, and sound could be regarded as any acoustic phenomena within the transmission medium, whether audible or not. He names the inaudible sounds those that human beings cannot perceive; those with too-low frequencies as 'infrasound' and those with too-high frequencies as 'ultrasound'. He charts the core scope of acoustics as 'fundamental physical acoustics', 'mechanical radiation in all material media', and 'phonons'. The broad ramifications of Pierce's thought may be seen in four major fields: earth sciences, life sciences, engineering, and arts. In these fields, the traditional subdivisions of acoustics are listed as follows: underwater sound; seismic waves; sound in the atmosphere; bioacoustics; hearing; psychoacoustics; electroacoustics; sonic and ultrasonic engineering; shock and vibration; noise; room and theatre acoustics; musical scales and instruments; and communication. Pierce's classification of acoustics demonstrates a list of the broad disciplines which are related to acoustics may never be completed and nowadays the term could be applied to more ubiquitous subdivisions or even to new fields altogether. For instance, Timothy G. Leighton suggests 'a "physical feel" for the acoustic interactions of acoustic fields with bubbles' in liquids in his book *The Acoustic Bubble* (Leighton 1994, xi). Another example is 'soundscape', which is the sound practice focused on environmental noise. The approach of soundscape involves the discussion of human perception and health, and cultural and social sciences, with multidisciplinary perspectives. The diversity of soundscape is comprehensively discussed in a book *Soundscape and the Built Environment*, edited by Jian Kang and Brigitte Schulte-Fortkamp (2016). The fundamental feature in common between all these fields is that acoustic phenomena are invisible and impermanent and exist through time and space. They may be perceived through the vibrations of matter. It may be considered that time and space are the key elements of the perceived 'materiality' of sound in an alternative context, and their characteristics can be shaped through both agencies of human and materials. In conventional music, sound can be analysed by frequency, duration, intensity, timbre, and texture. However, sonic experience in this context can be extended to unperceivable phenomena for humans, with the inaudible elements of sound waves that travel through matter. This means that sound in this comprehensive definition is quite extensive.

Beyond the analogue world Curtis Roads contributes another classification regarding the timescales of sounds in the digital age, which are shorter than conventional musical notes but longer than digital samples, in his well-known book *Microsound* (Roads 2001). Although the acoustic phenomena we perceive have been veiled in a long history of music, computation enables us to manipulate sound on varied and multiple elements, below or above the human inaudible level. According to Roads's theory, the human audible range in all acoustic phenomena is very limited. But even though the audible spectrum is normally limited from 20 Hz to 20 kHz, Roads's theory extends that spectrum from the infrasonic to the ultrasonic, with the audio frequency spectrum placed between these. Infrasonic frequency means frequencies below 20 Hz, which can be perceived by humans as vibration. In contrast, ultrasonic frequency refers to frequencies above 20 kHz, which exceed human audibility, and is sometimes applied to devices used to detect objects or measure distances well beyond 20 kHz, such as SONAR (Sound navigation and ranging) and ultrasonography. Regarding the intensity of sound, as well as the frequency, it is extended from subsonic to perisonic, with the audible intensity in between these. Subsonic intensity is too subtle for humans and cannot be perceived. Conversely, perisonic intensity is too loud and might seriously damage human ears.

Roads also proposes a new classification of sound timescales to fit with the digital age. With computer technologies, sound expression has been expanded to even inaudible timescales. In traditional music theory, the concept of timescales has been described with units such as notes, phrases, and musical structures. In fact, however, there should be much shorter timescales including inaudible ones below the note level, corresponding to the timescale which has been regarded as the shortest unit in traditional theory. In addition to this theory, Roads's approach to timescales, including those below our auditory threshold, is essential for new approaches with computation. He divides the timescales of all acoustic phenomena into nine levels: infinite, supra, macro, meso, sound object, micro, sample, subsample, and infinitesimal, in descending order (Roads 2001). In this classification, the timescales of macro (musical structure), meso (phrase), and sound object (note) correspond to the traditional timescales. In addition to these three are much longer timescales like supra (months, years, and centuries), and much shorter ones such as micro (millisecond), sample (microsecond), and subsample (nanosecond). Also added are the concept of the infinitesimal and the infinite as the longest and shortest timescales. Human beings perform different perceptual processes on each timescale, which may give varied perceptual effects.

In parallel to the development of new technologies for sound expression, the definition and classification of acoustic phenomena in sound composition has been expanded, as described in Pierce's definition of acoustics and Roads's theory of microsound. To consider new potentials of sound art in the new geological epoch, I am particularly interested in the imperceptible materials expressed through time and space as acoustic phenomena, like invisible air shapes. In my practice in this PhD research, I explored the temporal and spatial scales from the infinitesimal to the infinite, inspired by Bennett's view of 'vibrant matter'[29] and Morton's concept of 'hyperobjects'.[30] This

[29] See pp.38–39 in Chapter 2-1 for a description of 'vibrant matter' (Bennett 2010).

[30] See pp.39–40 in Chapter 2-1 for a description of 'hyperobjects' (Morton 2010; Morton 2013).

exploration aims to create a greater integration with the agency of matter[31] by utilising elements and natural processes through co-composition.

This approach is similar to recent trends in design to resolve social and environmental issues after the Industrial Revolution. In modern design, recent technological innovations have made it possible to design, develop, and improve the functions of matter for its sustainability and performance by employing nature's own elements and processes. In such a creative process, alternative methodologies of thinking and making are required that cross boundaries in design, science, engineering, and others. With these interdisciplinary perspectives, the creative outcome of artefacts can be integrated with elements and processes from nature in a new manufacturing way. I discuss some related approaches, such as smart materials,[32] 'biomimicry' (Benyus 2008),[33] and 'material ecology' (Oxman et al. 2015),[34] later in this sub-chapter and the next sub-chapter. These trends also lead to the collapse of our perception of the boundaries between natural and artificial matter. For a more contemporary understanding of matter in design, the following books explore interdisciplinary approaches in the new context of a better future: *Radical Matter: Rethinking Materials for a Sustainable Future* (Franklin and Till 2018), and *Why Materials Matter: Responsible Design for a Better World* (Solanki 2018).

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[31] See pp.21–22 in Chapter 1 for a description of 'agency' of matter.

[32] See pp.55–56 in Chapter 2-2 for a description of 'smart materials'.

[33] See pp.67–68 in Chapter 2-3 for a description of 'biomimicry'.

[34] See p.68 in Chapter 2-3 for a description of 'material ecology'.

Design and Materials

To allow the agency of matter into the compositional processes in sound art, it may be necessary to extend further the classification system of acoustic properties, not only of analogue and digital acoustic phenomena, but also of the 'materiality' of sonic experiences. Considering the materiality of sound, the creative methods that have been developed in the identification and selection of material in design and engineering may provide a clue, as some similarities can be seen in how humans experience products and art pieces. The British metallurgical engineer Mike Ashby and designer Kara Johnson have demonstrated, through a series of analyses of products, how material selection contributes to product personality and character. For instance:

> The amalgam creates product character – the way material and processes are used to provide functionality, usability, and satisfaction in ownership. This last – satisfaction – is greatly influenced by the aesthetics, associations, and perceptions that the product carries, a combination that we shall refer to as product personality. The overall character of the product is a synthesis of its functionality, usability, and its personality. (Ashby and Johnson 2003, 24)

Ashby and Johnson assert that 'products' are set by the 'context', oriented according to the fundamental questions of who? where? when? and why? for user experience, which are connected to both physiological and psychological aspects of the products (Ashby and Johnson 2003). The 'product physiology' is created by the 'materials' and 'processes', which need to be selected to meet the essential requirements of the products, such as functions and features. The combination of materials and processes creates ‘personality’ and ‘usability’ for ‘product psychology’, and thus successful operation and interaction between products and users.[35]

This dissection may be applied to art, by replacing ‘products’ with ‘art piece’ within a strong ‘context’, involving both ‘product physiology’ including materials and processes, and ‘product psychology’ including personality and ‘experience’. For art pieces, the ‘personality’ in product psychology may play an important role, which is constructed by the following three elements. In the first, ‘aesthetics’ is created by colour, form, feel, taste, and sound. In the second, ‘associations’ are what the work indicates in the way of experience, such as wealth, military hardware, aerospace, and so on. In the third, ‘perceptions’ are the observer’s emotions. Aesthetic attributes in particular, delivered by the sound and visual components of art pieces, are grasped by the human senses.[36]

Ashby and Johnson present a more elaborated view of material selection in their book *Materials and Design: The Art and Science of Materials Selection in Product Design*. They look into aesthetic attributes as one aspect of multi-dimensional materials in both design and engineering, in relation to the five senses: sight, touch, sound, smell, and taste (Ashby and Johnson 2010). The authors give an example of the acoustic attributes – how humans can sense sound – in the context of materials. They illustrate a multi-dimensional scaling (MDA) map of acoustic properties, which graphically maps

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[35] Ashby and Johnson illustrate the dissection of product character in a figure; see p.27 in the journal article *The Art of Materials Selection* (Ashby and Johnson 2003, 27).

[36] Ashby and Johnson also illustrate the components of product personality in a figure; see Ashby and Johnson (2003, 28).

classes of materials with the relationship between acoustic pitch and brightness.[37] According to this map, materials are grouped into four major categories with similar acoustic properties: metal, ceramic, natural, and polymer. Two properties of materials – stiffness/elasticity and density – are important in determining the sound pitch of a struck object. The acoustic response can be described not only by pitch but also by brightness, which is the inverse of 'damping' that represents a dull and muffled sound.

In addition, the British artist and material expert Zoe Laughlin has attended to the materiality and acoustic properties of sound in art and science as a part of her projects. She addresses the question of how a material can be defined in the context of the arts. She suggests that the use of the term 'materials' in the description of an art work refers to the components of the work, which is the matter used to create the output. In this case, 'materiality' can not be defined by mere scientific identification:

> A material becomes the input in the process of physical construction that influences the properties of that which is constructed as a result of the material's embedded 'materiality'. This materiality is associated with classifications ranging from a qualitative aesthetic, sensorial, and behavioural appreciation of a material, to the specific cultural resonance of a material and its ability to connote meaning. (Laughlin 2010, 23)

Laughlin aims to explore the sensoaesthetic properties of materials, such as aesthetics, sensuality, and emotion, by combining both scientific and aesthetic aspects of materials for the artist and designer rather than the scientific researcher. In some of her projects, the sense of touch is used, that is, warmth, softness, and roughness. *Tuning Forks* (Laughlin, Naumann, and Miodownik 2008) is one research

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[37] Ashby and Johnson demonstrate the acoustic attributes of materials in a figure; see Ashby and Johnson (2010, 79).

project about the sensoaesthetic theory of materials. The researchers made a set of tuning forks of identical shapes out of different materials in order to explore the acoustic properties of matter. They assumed that the sounds generated by the tuning forks were influenced by three factors – the ‘shape’, the ‘density’, and the ‘elastic modulus’ of the material – which results in sound qualities such as frequency, duration, and amplitude. Laughlin also contributed a series of events including *The Sound of Materials* (2006–2008) and *What Can the Matter Be?* (2008). These events focus on the characteristic of sound through physical and material properties (Laughlin, n.d.(b); Laughlin, n.d.(c)). Laughlin’s ongoing project *The Performativity of Matter* (2009–) is a unique performance that demonstrates the nature of inanimate materials (Laughlin, n.d.(a)).

In the creative industries, such as architecture, design, fashion, and engineering, there is a trend for using smart materials and emerging technologies to develop more efficient solutions. ‘Smart materials’, also called intelligent materials or responsive materials, is a generic term for designed materials that perform properly and autonomously in response to changes in the environment and conditions of the material itself, by utilising the inherent properties of substances or by combining materials. For instance, various materials made of metal, plastic, and fabric have a self-recovery function – the materials repair themselves when they are damaged. Smart materials have been applied in diverse fields; however, it is difficult to give an overview of their properties and methods in each field. One attempt to make a comprehensive view of the approaches in relation to smart materials for architects and designers is Michelle Addington and Daniel Schodek’s book *Smart Materials and New Technologies: For the Architecture and Design Professions* in 2005. They define smart materials as follows:

> Defined as ‘highly engineered materials that respond intelligently to their environment’, smart materials have become the ‘go-to’ answer for the 21st century’s technological needs. (Addington and Schodek 2005, 1)

Addington and Schodek also list four groups of fundamental features which can distinguish smart materials from other materials: 1) ‘property change capability’, 2) ‘energy exchange capability’, 3) ‘reversibility’, and 4) ‘discrete size/location’ (Addington and Schodek 2005, 79). The first two features determine the physical characteristics of smart materials. Addington and Schodek simplify the difference between these two according to the energy fields and mechanism of the conversion between materials and input energy. In the authors’ words:

> A simple way of differentiating between the two mechanisms is that for property change type, the material absorbs the input energy and undergoes a change, whereas for the energy exchange type, the material stays the same but the energy undergoes a change. (Addington and Schodek 2005, 80)

The third feature, ‘reversibility’ (or bi-directionality), is something smart materials in the first two groups often have. This is the ability of the material to change the properties of itself in an opposite direction, or to exchange input and output energies in a certain direction. Finally, the fourth feature ‘discrete size/location’ is one of the most fundamental features for all materials in the four groups. According to Addington and Schodek’s description, ‘a component or element composed of a smart material will not only be much smaller than a similar construction using more traditional materials but will also require less infrastructural support’ (Addington and Schodek 2005, 81).

As discussed above, Ashby and Johnson's viewpoint of acoustic properties of materials, Laughlin's sensoaesthetic theory and the recent endeavour of smart materials can be practical clues to ways of considering and creating more seamless experiences between sound and materials by employing nature's own elements and processes. Since the motivations and methodologies of art and design are not necessarily the same, art does not completely follow the same creative method of this trend. However, aesthetic explorations in interconnected relationships with materials may play a role in adding a new context to sound art in the Anthropocene. For sound art in a post-anthropocentric[38] context, the further process of how material selection composes sonic and visual expression should be addressed, in order to compose more multi-dimensional experiences.

In concluding this sub-chapter, in my research, I do not focus only on the physical characteristics of sound, but also on the temporal and spatial attributes of its reception, as the perceived 'materiality' of acoustic phenomena. By considering sound as such a phenomenological 'matter', its existence becomes perceptible in some ways through the vibration of matter in a space. Matter is constantly changeable and unstable through its interaction with its environment. Similarly, sounds also interact with their environment, and their characteristics can be shaped through both humans and materials. Hence, time and space as the materiality of sound are possible parameters by which to sense unperceivable domains through perceptible objects.

[38] See pp.18–19 in Chapter 1 for a discussion of my own use of the term 'post-anthropocentric'.

2-3. Generative Processes of Matter

In his book *Nature, Man and Woman*, initially published in 1958, the British philosopher Allan Watts describes the boundary between the natural and the artificial world, providing the fundamental distinction between the organic and the mechanical in generative processes as follows:

> [F]rom the standpoint of Taoist philosophy natural forms are not made but *grown*, and there is a radical difference between the organic and the mechanical. Things which are made, such as houses, furniture, and machines, are an assemblage of parts put together, or shaped, like sculpture, from the outside inwards. But things which grow shape themselves from within outwards. They are not assemblages of originally distinct parts; they partition themselves, elaborating their own structure from the whole to the parts, from the simple to the complex. (Watts 2012, 39)

According to Watts's concept, the 'growth' of matter makes it more natural and organic. Recent advances in chemistry and biology have made it possible to mimic these generative processes in matter. This sub-chapter highlights the generative processes of matter; how we can position and classify the generative processes in the organisation of matter from a scientific perspective, and how we can incorporate the generative processes of matter into creative output in art and design. From a scientific point of view, all life-forms in nature are composed of non-living matter. However, it can be said that both biologically living or non-living matter has vitalism[39]; a sort of intention for authorship and making as creative forces can emerge from matter through its decision making and/or behaviour.

[39] See pp.20–22 in Chapter 1 for a discussion of my own use of the term 'vitalism'.

In the mid-nineteenth century, Darwin developed the theory of evolution, well known as Darwinism. He published the famous book *On the Origin of Species by Means of Natural Selection* in 1859. The core of his theory is that biological evolution occurs by the ‘natural selection’ over generations of species that are well-adapted to their environment, creating variations of species through evolutionary divergence (Darwin 1861, originally published in 1859). This is to say, surviving in the natural environment requires the selection of unintentional mutations to direct evolution.

> Owing to this struggle for life, any variation, however slight and from whatever cause proceeding, if it be in any degree profitable to an individual of any species, in its infinitely complex relations to other organic beings and to external nature, will tend to the preservation of that individual, and will generally be inherited by its offspring. The offspring, also, will thus have a better chance of surviving, for, of the many individuals of any species which are periodically born, but a small number can survive. I have called this principle, by which each slight variation, if useful, is preserved, by the term of Natural Selection, in order to mark its relation to man’s power of selection. (Darwin 1861, 61)

Darwin’s theory refers to a mechanistic evolution by accidental mutation without any specific direction, which is not the evolutionary progress of the internally prepared structure.

In 1911, the French biologist Stéphane Leduc published *The Mechanism of Life*. Leduc uses the term ‘synthetic biology’ to describe the synthesis of life by means of non-living materials. His main focus is on the chemical and physical mechanisms of life, especially the synthesis of cells rather than molecules. He finds the complexity of life mechanisms in physico-chemical processes, through a series of experiments that showed a range of phenomena like those of living entities, such as morphogenesis[40] and evolution, generated by inorganic matter. He defines a ‘living being’ as a transformer of energy, matter, and form.

> The true [sic] definition of a living being is that it is a transformer of energy, receiving from its environment the energy which it returns to that environment under another form. All living organisms are transformers of energy.
>
> A living organism is also a transformer of matter. It absorbs matter from its environment, transforms it, and returns it to its environment in a different chemical condition. Living things are chemical transformers of matter.
>
> Living beings are also transformers of form. They commence as a very simple form, which gradually develops and becomes more complicated. (Leduc 1911, 3–4)

Leduc suggests that organic forms and vital actions could be generated by the contact of two different liquids as chemical forces, and osmotic pressure and diffusion as physical forces. The matter of living organisms includes two types of solutions: colloids and crystalloids. This approach has been developed into the modern study of synthetic biology, which is now a major field of research, called ‘protocells’, which may be designed as the intermediate state of bodies between living and non-living. The general definition of protocells in prebiotic chemistry and the origin of life is ‘hypothetical precursor structures of the first cells, which are assumed to have been formed at the origin of life about 4 billion years ago’ (Walde 2010).[41]

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[40] According to the *Oxford English Dictionary*, ‘morphogenesis’ refers to ‘[t]he origination and development of morphological characters; morphogeny’ (OED Online 2019h).

[41] More details of the concept and recent studies of ‘protocells’ are discussed on pp.62–67 in this sub-chapter.

Around a decade after Leduc, Oparin proposed the theory of the chemical evolution of life, based on theories of panspermia. Panspermia is one of the hypotheses of the origin of life, which states that life exists all over the Universe, and the origin of life on the earth originated from microscopic spores, such as microorganisms or biochemical compounds, that propagated through other celestial bodies. The term was first mentioned by the Greek philosopher Anaxagoras in the fifth century BC, who assumed that 'seeds of life are present everywhere in the Universe' (Rampelotto 2010, 1). Oparin's focus is on how life initially began, rather than how life evolves. According to his theory, abundant primary organic compounds such as hydrocarbons are synthesised from inorganic substances in the atmospheric constituents on the primitive earth, and they gradually become complex organic substances such as carbohydrates and proteins. These organic substances were then dissolved in the primitive ocean, where 'coacervates' droplets are formed. According to the Mexican biologist Antonio Lazcano, '[c]oacervates are charged, microscopic organic colloidal droplets that can concentrate organic materials existing in the medium' (Lazcano 2010, 7). Coacervates are a particular form of matter that has little to do with living systems and are used as a model system for protocells. In recent studies, there are some reports that particles made of macromolecules such as coacervates are important for the origin of life and intracellular systems, in the form of liquid droplets formed by liquid-liquid phase separation (LLPS) (Aumiller et al. 2016). This idea of chemical evolution was first presented at a meeting of the Moscow Botanical Society in 1922 and developed in Oparin's first book *The Origin of Life* (1938, originally published in 1924). He asserts:

> [T]his need not lead us to the conclusion that there is an absolute and fundamental difference between a living organism and lifeless matter. (Oparin 1938, 246)

> The complex combination of manifestations and properties so characteristic of life must have arisen in the process of the evolution of matter. (Oparin 1938, 246)

All living entities on the earth are composed of atoms, which are the basic building blocks of all matter, and the molecules composed of the atoms make up chemical compounds that are not living themselves. Although the periodic table of the elements today shows over 100 elements, all living organic matter is made up of six major elements, known by the acronym CHNOPS: carbon (C), hydrogen (H), nitrogen (N), oxygen (O), phosphorus (P), and sulfur (S) (Cockell 2015). There are also many minor elements, such as iron (Fe) and zinc (Zn), that are essential for life. The atoms of the six major elements combine to form the organic molecules that comprise living matter. The main constituents of living matter are water and organic compounds, and all life-forms are carbon-based. Most of the organic compounds in living matter, including cells, can be classified into the four major groups of carbon-based molecules: proteins, nucleic acids (DNA and RNA), carbohydrates, and lipids (Cooper and Hausman 2007). These constituents have different functions and are integrated into a living system with some essential characteristics, such as providing energy, forming their own structure, and conveying signals and genetic information. In modern science, there is a research trend to use protocells to imitate these fundamental characteristics of living mechanisms to create new living systems in artificial ways.

An artificial life model – a protocell – is a simple model of a life-form that can be produced in the laboratory. The term 'protocell' was first used by Jack W. Szostak, David P. Bartel, and P. Luigi Luisi in their article of 2001, in which they define life as follows:

> Defining life is notoriously difficult; its very diversity resists the confines of any compact definition. An operational approach focuses on identifying simple cellular systems that are both autonomously replicating and subject to darwinian evolution. (Szostak, Bartel, and Luisi 2001, 387)

In their early idea of the protocell, they define life as follows; '[w]e can consider life as a property that emerges from the union of two fundamentally different kinds of replicating systems: the informational genome and the three-dimensional structure in which it resides' (Szostak, Bartel, and Luisi 2001, 387). Strictly speaking, in more recent discussions, the term 'protocell' is used in two ways; the one is the protocell positioned as the ancestor of all living cells in nature in the story of the origin of life, and the other is the protocell as a cell-like object artificially made from scratch. My own use in this thesis refers to the latter meaning, what a research group led by Szostak calls 'model protocells' (Chen, Roberts, and Szostak 2004).

This model is composed of non-living chemical materials and has some biological properties of life. This chemical life-form imitates a primitive cell and has a very simple structure compared to the complex system of biological life. However, it may still be considered as a system that integrates three essential functionalities of living systems: container, metabolism, and genes (Rasmussen et al. 2009). Rasmussen and colleagues define the functionalities of the chemical living systems as follows:

> [C]hemical instances of such forms of life must embody the three operational functionalities in three integrated chemical systems: a *metabolism* that extracts usable energy and resources from the environment, *genes* that chemically realize informational control of living functionalities, and a *container* that keeps them all together. We will use the term *protocell* to refer to any realization of these three functional components. (Rasmussen et al. 2009, xii–xiv)

The concept of establishing the relationship between these functionalities as a minimal living system was originally proposed by Manfred Eigen and Tibor Gánti (Rasmussen et al. 2009). Eigen's research concerns the informational principle of the macroscopic self-organisation of matter as a minimal description of life, involving selection and evolution at molecular levels (Eigen 1971). Gánti asserts that the minimal description of life that could form a cell should be subdivided into three subsystems: the cytoplasm, the genetic material, and the cell membrane, arguing that living systems are functioning systems that work in a special order (Gánti 1975).

At the TED Salon in London in 2011, the scientist Martin Hanczyc gave a talk titled *The Line Between Life and Not-Life*. Hanczyc's research focus is artificial living systems made of chemical components. In his talk, he simplifies living systems into the following three characteristics: containment as a body, metabolism, and inheritable information. The body plays a fundamental role in maintaining the boundary between the living organism and its environment. The metabolism is a process for sustaining life by the chemical transformation of resources in the environment into energy. Inheritable information such as DNA is a genetic archive that can be passed on to the next generation. By assembling these characteristics, it is possible to make some generative processes, including movement, reproduction, and evolution (Hanczyc 2011).

In the modern study of protocells, the artificial living system is experimented with to create generative processes such as movement, reproduction, and evolution, and the combination of these processes, through chemistry and physics. The combination of container and metabolism is experimented with to produce the movement and reproduction of the living systems, and in the future the combination of all three processes including genes could create more complex life mechanisms, such as evolution. Hanczyc demonstrates artificial cellular models that mimic the primitive behaviours of life of encapsulation, growth, and division (Hanczyc 2003). His principal approach is focused on movement as one of the essential characteristics of artificial life, produced by simple ingredients consisting of certain oil droplets and a watery environment. He calls various patterns of self-propelled movement non-equilibrium chemical systems, which have self-organised compartments as their 'container', and materials and energy as their 'metabolism'. These movements are chemically and physically related to other components in the materials' environment, but they seem to sense and react with them in their decisions to move, like natural life. These could be interpreted as intentional actions. Although this artificial behaviour is so far unlike the mechanisms of natural living systems, it indicates potential applications for the creation of artificial life.

Research into protocells has attracted a lot of attention from not only scientists but also artists, architects, and designers, for ideas, methodology, and materials, among other things. The film project *Protocell Circus a.k.a. A 'Natural History' of Protocells*, by Rachel Armstrong and Michael Simon Toon (2010), demonstrates the life-like movements of protocells synthesised in a laboratory, with anthropomorphic[42] subtitles emphasising their behaviours and interaction (Armstrong and Toon n.d.). Armstrong and Toon assume that protocells are the beginning of life, or even the birth of our consciousness. The piece exhibits the evolutionary hypothesis that our behaviour may be determined as a reflection of the behaviour of protocells, not that the protocells mimic our behaviour. Armstrong's

[42] See pp.19–20 in Chapter 1 for a description of 'anthropomorphism'.

research is about 'living architecture' that has a self-repairing function, by integrating with protocells as one of its approaches. The protocells shown in the film are called the 'Bütschli dynamic droplet system', which is an oil–water droplet system originally proposed by the zoologist Otto Bütschli in 1898 and reconstructed more recently by Armstrong in collaboration with Hanczyc (Armstrong and Hanczyc 2013).

Philip Beesley, a Canadian architect and artist, demonstrates geotextile forms and the protocell circulation system in his *Hylozoic Ground* (2010) project, made in collaboration with Armstrong (Beesley and Armstrong 2011). He offers 'near-living architecture' as a part of a collaborative project, the *Hylozoic Series*, with interdisciplinary researchers and collaborators in Canada, the USA, and Europe. This aims to create a synthetic organic environment with a metabolic system (Beesley 2014). A metabolism is a function for transforming the substances of cells and organisms into other substances in one of two ways, catabolism and anabolism, by absorbing or producing energy to maintain their state of life. This is the smart way by which matter continues to live sustainably within its own environment. Beesley's works offer a kinetic mesh structure that mimics life processes by integrating nature and technological materials. His protocell series, *Protocell Field* (2012), *Protocell Cloud* (2012), and *Protocell Mesh* (2012–2013), creates kinetic structural environments using protocells and by processing carbon dioxide in the atmosphere (Beesley 2016b; Beesley 2016a; Beesley 2016c). The structure of these pieces consists mainly of two elements: the mesh structure of the canopy and the carbon capture filters of the protocells. Beesley's pieces use sound and light to show the organic forms and the behaviour of wave motions spreading to the whole structure. These structures interact with their surroundings and indicate a new context for architecture that emphasises a stimulated relationship with its viewers that is more like literature than architecture (Beesley 2013).

The Mechanism of Life – After Stéphane Leduc (2013) by Catts, Zurr, and Corrie van Sice is an installation piece that is inspired by the concept of Leduc's *The Mechanism of Life* (1911). The artists created a 3D printer-like system for the prototyping of protocells and attempted to automatically re-create the temporary life of primitive cells. These cells are made of oil droplets in solution and apply one of the simple protocols proposed by Leduc more than one hundred years ago. The 'life' created lasts for a few minutes, showing unstable organic forms. The artists reveal the potential issues in making a sort of life automatically printable (Science Gallery Dublin 2013).

Influenced by these historical backgrounds in science and philosophy, designers also take new innovative methodologies to develop and create products by incorporating the natural materials and processes in unconventional ways in order to solve complex human issues in our society and reduce environmental impact. The following approaches in design are similar to the creative tendency in modern art that explores the intermediate state between natural/artificial or living/non-living matter, such as Ascott's concept of 'moistmedia' (2000)[43] and Kac's proposition of 'bio art' (2007),[44] as discussed in Chapter 2-1. For instance, the American biologist Janine Benyus proposes the ecological concept of 'biomimicry' in her book *Biomimicry: Innovation Inspired by Nature* published in 1997 (Benyus 2008). Biomimicry is a term that combines the Greek 'bios' (life) and 'mimesis' (imitation).

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[43] See p.42 in Chapter 2-1 for a description of 'moistmedia'.

[44] See pp.42–43 in Chapter 2-1 for a description of 'bio art'.

Inspired by the mechanism of nature and organisms, this framework aims to create products or develop technologies by mimicking the design and processes of 'nature's masterpieces – photosynthesis, self-assembly, natural selection, self-sustaining ecosystems, eyes and ears and skin and shells, talking neurons, natural medicines, and more' (Benyus 2008, 2). Benyus suggests three ways to consider ideas that adapt natural elements and processes from the viewpoint of biomimicry. First is the mimicry of form, which is mimicking natural forms and structure. Second is the mimicry of pattern, which imitates the processes created by natural things. Third is the mimicry of ecosystem, that is, the whole system of nature. The main objective of biomimicry is to emphasise sustainability and environmental issues.

In addition, an emerging design approach called 'material ecology' is represented by the American–Israeli architect Neri Oxman, who is organising the Mediated Matter research group at the MIT Media Lab (Oxman et al. 2015). This approach is defined as the study of designing products and processes that integrates the world of artefacts with ecology in a natural environment. The outcome of this concept is ecological objects in organic forms that merge elements of design such as computation, digital fabrication, and materials in an inseparable relationship. According to Oxman and colleagues, 'Material Ecology aims to bridge this gap by increasing the dimensionality of the design space through multifunctional materials, high spatial resolution in manufacturing and sophisticated computational algorithms' (Oxman et al. 2015, 1).

Throughout the theoretical research in this sub-chapter, I have focused on the generative processes of matter to explore the boundary between the living and the non-living, described by current theories in science, art, and design. Scientifically speaking, all natural life-forms are made of chemical compounds and have chemically evolved. Recent technologies have made it possible to create from scratch life-like entities and artificial creatures, like protocells, that have life-imitating properties. These new forms of creating and engineering can provide a sophisticated clue to resolving issues of sustainability and the environment that encourage the emerging relationship with the earth in the new geological era. Accelerated by these technological developments and applications in various fields, the boundary between natural and artificial matter would increasingly collapse.

The explorations of generative processes of matter in theory and practice discussed above are not aimed at practical ways of thinking and creating sonic and visual expressions in sound art. In this research, I consider the boundary between living and non-living matter by looking into life-like behaviours of both biologically living and non-living matter through sound art practice. As discussed in Chapter 1, inspired by the concept of 'autopoiesis' (1980) by Maturana and Varela,[45] the term 'life-like' used in this thesis refers to the biological properties of life found in the systemic organisation of matter, regardless of whether it is biologically living or non-living. To consider some characteristics of what makes matter be perceived as living, I adopt the proposition that there should be vitalism and creative force either in living or non-living matter. From the standpoint of sonic and visual anthropomorphism, the autonomous reactions of matter, particularly their decision making and behaviour, can be recognised as life-like behaviours motivated by the agency of matter.[46] In my practice, I incorporate the agency of matter into my compositional process to co-compose sonic and visual expression with materials as co-authors and co-makers. This creative approach is similar to

[45] See pp.22–23 in Chapter 1 for a description of 'autopoiesis'.

[46] See pp.21–22 in Chapter 1 for a description of 'agency' of matter.

Benyus's idea of biomimicry and Oxman's research of material ecology. My methodology of co-composition expands the sonic and visual expression to unexpected directions and creates surprising outcome that humans intentionally cannot.

2-4. Summary

In this PhD thesis, I explore the life-like behaviours found in the generative processes of matter as the main subject of this research. Through my practice, I created and presented sound art works by co-composing with materials in a way that incorporates the autonomous behaviours of those materials into the compositional processes. Through the exhibitions of my works, I clarify the diversity of sonic and visual expression caused by the behaviours of matter themselves and the potential life-like processes that matter originally have.

The background of this research is that there are social and ethical discussions around the fact that the boundaries between the natural and the artificial are becoming blurred, driven by recent technologies that create, manipulate, modify, and maintain life-like materials, such as microchip implants, electronic skin, machine learning, and artificial psychology. Such a relationship between natural and artificial matter is constantly evolving in a complex manner through their multi-directional interactions. Therefore, it is difficult to clearly define how we should separate our perception of the boundary between the natural and the artificial.

One of the causes of the above issues relates to the fact that the boundary between natural and artificial matter has been discussed from the anthropocentric perspective. From the standpoint of modern ecology and geology, I therefore reinterpreted matter in the post-anthropocentric[47] context, by linking this blurred relationship with social and ethical discussions related to the Anthropocene, OOO

[47] See pp.18–19 in Chapter 1 for a discussion of my own use of the term 'post-anthropocentric'.

(Harman 1999; Harman 2002; Harman 2011), and philosophical theories of the boundary between human and nonhuman including the discussions by Haraway, Bennett, and Morton. Specifically, my methodology deeply relates to the concepts of 'vibrant matter' (Bennett 2010) and 'hyperobjects' (Morton 2010; Morton 2013). Inspired by these ideas, this doctoral research explores new relationships of co-composition between natural and artificial matter by connecting them together, not separating them. Ultimately, I found vitalism[48] of matter in the autonomous behaviours that all matter, either biologically living or non-living, potentially has.

In this thesis, I use the term 'co-composition' as a core concept that I define as follows:

> The term 'co-composition' used by the author refers to the creation of sonic and visual modes of expression through the compositional process by collaborating with materials – which indicates that the author sets/facilitates a frame that leaves a blank space in which materials can behave freely and incorporates the unpredictable reactions produced by the materials themselves as 'co-author' and 'co-maker' in the process of composition.

In order to engage with the co-composition method in practical ways, the artist sets a certain level of how much humans displace their notions at the centre of creative practice, depending on the materials in each art work. This compositional process elicits unexpected and surprising creative reactions from nonhuman materials that humans cannot achieve; it demonstrates the limitations of anthropocentrism

[48] See pp.20–22 in Chapter 1 for a discussion of my own use of the term 'vitalism'.

and is a reflection of a post-anthropocentric art practice. As human sensory perception is limited, our decision making and behaviour are always made within our perceptible range. On the other hand, nonhuman materials can act freely regardless of our perception. As long as the creative outcome is presented as art works, the audience of art works is human. However, a part of the creative outcome produced by nonhuman materials should present some unique elements that exist outside of our perceptible range of time and space. These unperceivable elements can be reflected in the co-composed outcome through the interactions between nonhuman materials and/or the interactions between human and nonhuman and perceived in other forms within our perceptible range.

The purpose of this research is to create new sonic and visual modes of expression through co-composition, by reinterpreting matter from a post-anthropocentric perspective and incorporating the autonomous reactions found in the generative processes of matter into the compositional processes of sound art works as co-author and co-maker. Two questions form the core of this research. How can life-like behaviours of matter be portrayed through sonic and visual modes of expression? And in what ways might the expression of life-like behaviours be grasped by human perception? In order to verify these research questions, I conducted scientific experiments on life-like behaviours in a lab setting, and created sound art works by applying the information, results, and consideration obtained there into their sonic and visual elements.

The distinctive feature of this research is that it focuses on the applicability to sound art works of methodologies – such as biology, ecology, and philosophy – that have not been well dealt with in the framework of conventional sound art research. The conventional research of sound art has often considered its expression in the historical context related to art, such as musical history and art history. This research seeks the intersection of philosophical discussions, including OOO and nonhuman theory, with sound art as a new methodology of expression and materials in the creation of sound art works. In addition to the conventional exploration of sonic and visual expression, I take a novel research method that combines biological experiments in a lab environment, ecological study, and philosophical methodologies including OOO. The creative outcomes which incorporate unpredictable behaviours created by matter other than the artist into the compositional processes are rich in unexplored creativity. Since nonhuman/inhuman art practice engaged with sound is an emerging field, this practice-based research that integrates the scientific experiments in a lab environment and the theoretical research of sound art represents a unique approach within this field.

The related research trends focusing on the autonomy of materials include smart materials (Addington and Schodek 2005) and unconventional computing (Braund and Miranda 2014; Miranda, Adamatzky, and Jones 2011; Miranda 2017).[49] These research fields focus on the practical development and application of technology, rather than the theoretical discussions as an extension of art history. For comparison, a research that explores the sensory characteristics of materials for artists and designers by combining the scientific and aesthetic aspects of the materials is discussed by Laughlin in her sensoaesthetic theory of materials (Laughlin 2010). Such a creative output, which aims at a seamless experience within the boundary between natural and artificial matter, has also been explored by various artists in the field of art. As examples, Ascott's 'moistmedia' (2000) and Kac's 'bio art' (2007) can be discussed as artistic expressions by means of life itself, biological materials, or biotechnology.

[49] See p.81 in Chapter 3-1 for a discussion of one approach to 'unconventional computing'.

However, since much of this research focus on visual expression, academic research which explores the possibilities for new sonic and visual modes of expression in sound art across disciplines, like my research, has not yet been established.

This research pursues the possibility of a new methodology of sonic and visual expression that incorporates life-like behaviours of matter into the composition processes. It will show examples of application through the creation of actual sound art works, to verify whether it is possible to create a variety of sonic and visual expression by adding the elements autonomously driven by matter itself motivated by the agency of matter.[50] The processes of creating art works in this research involve not only pursuing sonic and visual expression, but also scientific experiments and philosophical methodologies; it is significant to embody the output through these processes as artistic expression. The approach of this practice-based research, which conducts sound art research from the perspectives of both theory and creative practice, is able to consistently carry out the entire processes of embodying what I have obtained from theoretical research as a creative outcome. It can be applied not only to sound art, but also to other fields, such as technology, biology, ecology, design, and material engineering. Therefore, this research would give a wide range of impacts in the fields of art, design, philosophy, and science, and can be contribute intellectually beyond the academic sphere as well.

[50] See pp.21–22 in Chapter 1 for a description of ‘agency’ of matter.

3. Practice

3-1. Life-like Behaviours of Matter

Through dramatic advances in life sciences and in applied technologies that can create and manipulate living materials in the twenty-first century, conventional human understandings and perception of life may no longer be sufficient. How do we re-define living matter in the Anthropocene? What gives matter the biological properties of life? In the early stages of my PhD process, I began to investigate autopoietic[51] behaviours in complex living mechanisms through laboratory-based experiments. To look into these living mechanisms, I visited SymbioticA, the Centre of Excellence in Biological Arts at the University of Western Australia and followed this up with research at the SymbioticA Exploratory Residency as a resident artist from August to September in 2016.

A cell is the minimum unit of the structure of living organisms, and their growing process reveals the fundamental matter of life and its biological properties. At SymbioticA, I researched the tissue culture of a mouse myoblast cell line, called C2C12. C2C12 cells are skeletal muscle cell lines found in mice, which develop the forces that allow the bones and other structures of the body to move (McMahon et al. 1994). The C2C12 myoblasts fuse and differentiate into myotubes showing dynamic morphological changes through rapid development day by day. Throughout my observation over a series of experiments, I found three distinctive life-like behaviours in the growing process. I understood these behaviours to be life-like features of generative processes in the organisation of matter, regardless of

[51] See pp.22–23 in Chapter 1 for a description of 'autopoiesis' (Maturana and Varela 1980).

whether the materials are either biologically living or non-living. I decided to explore these life-like features in my artistic practice to create alternative sound expressions that were co-composed between natural and artificial matter; I discuss each of these within sub-chapters 3-2, 3-3, and 3-4.

Tissue culture (or 'cell culture') is a technique in biotechnology in which living cells or tissues, taken from an animal or plant organism, are artificially grown or maintained in vitro. The term 'tissue culture' was coined by the French surgeon and biologist Alexis Carrel and his assistant Montrose Burrows in 1911 (Carrel and Burrows 1911). Their revolutionary technique has the potential to continuously create new cultures from old ones with no limit to generations, without obtaining tissues from primary cultures.

This technique has given artists new inspirations and ways of expression using biological materials as a medium. For instance, the project *Ear on Arm* (1996) by the Australian performance artist Stelarc proposes: 'alternate anatomical architecture – the engineering of a new organ for the body: an available, accessible and mobile organ for other bodies in other places, enabling people to locate and listen in to another body elsewhere' (Stelarc, n.d.). In this project, he surgically grew a third ear on his own arm, which extended his sense of hearing through an implanted microphone, and he shares the sound on the internet to an unspecified public through a wireless internet connection. More recently, the artist Diemut Strebe created a living 3D printed replica of Vincent van Gogh's ear, entitled *Sugababe* (2014). This ear was grown from a fragment of cartilage taken from Vincent's male descendant Lieuwe van Gogh, using tissue engineering, and contains Van Gogh's genetic information and genetically engineered components using the CRISPR technique and bio-printing technology (Strebe, n.d.). These projects imply a radical reconsideration of the intermediate domain between living and non-living, such as: what life is and how 'living' materials can be made? What is the boundary between the living and the non-living? How might life be created, either naturally or artificially? The use of these materials in art touches on our understanding and perception of life and death and our future vision of life with biotechnology.

To explore the emerging technologies and ethical considerations of living materials in the new field of art, a research initiative called the *Tissue Culture & Art Project* was established in 1996 by Catts and Zurr. They propose the term 'Semi-Livings' to refer to living fragments that remain alive in artificial environments in certain conditions, outside of the body (Zurr 2008). In Zurr's doctoral dissertation, she describes the concept of 'Semi-Livings' as follows:

> The Semi-Livings refers mainly to living tissue constructs that have no biomedical purpose. In the case of Catts and Zurr these evocative entities are created for the sole purpose of art. The Semi-Livings are unique examples of a growing class of objects/subjects that are increasingly populating our made environment. (Zurr 2008, 5)

The Tissue Culture & Art Project aimed to create 'semi-living objects' through the 'artistic manipulation' of living tissues, by using biological technologies such as tissue culture (Catts and Zurr 2002).

During my residency at SymbioticA, I experimented with C2C12 cells to culture them and observe their development for around a month. My research during this residency was supported by Catts and

Zurr. This experiment was conducted at SymbioticA's PC2 safety laboratory,[52] at the School of Human Sciences at the University of Western Australia.[53] The following pictures (Figure 4) are taken from an inverted microscope at 200x magnification during a time-lapse recording, capturing one frame every one minute over the course of 48 hours.

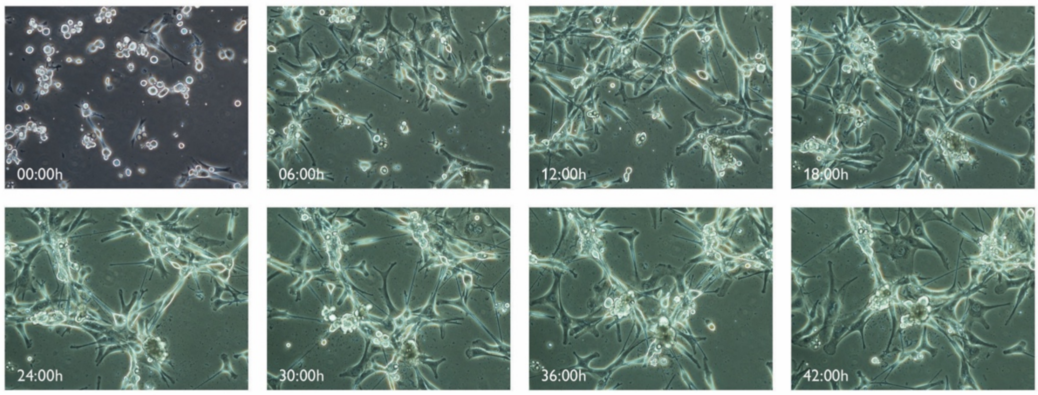

Figure 4 The growing process of C2C12 cells, in my experiment at SymbioticA, School of Human Sciences, The University of Western Australia. Observed with 200x magnification inverted microscope. The snapshots of the time-lapse recording by Mari Ohno (2016).

The movie of this time-lapse recording is in the Appendices; see the 1-1-1. time-lapse recording of C2C12 cells, in the folder labelled *1-1. lab experiment* in the folder of *Appendix 1* on the attached USB memory stick.

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[52] Laboratories are classified into four Physical Containment levels (termed PC1–PC4 laboratories), and these levels of laboratories applicable to research and diagnostic work with corresponding microorganisms which are classified into four risk groups, based on several criteria (termed Risk Groups 1–4) (Dixon, n.d.).

[53] As I was working with animal cell lines which are commercially available, there was no requirement for ethical clearances.

These pictures show that C2C12 myoblasts grow into myotubes in standard nutrient media, which is Dulbecco's modified Eagle's medium (DMEM) with 10 percent Fetal Calf Serum (FCS) and 1 percent Penicillin/streptomycin (Pen/Strep), in an incubator at 37°C and 5 percent CO_2. In my observation, a series of basic experiments demonstrated three distinctive features that suggested the biological properties of life in the growing process: 1) cell propagation, 2) once the FCS was reduced from 20 percent to 2 percent, the myoblasts began to differentiate into myotubes (multi nucleus cells), and 3) some of the myotubes then began twitching spontaneously. For my PhD research, I simplified these features into three life-like behaviours that can be observed in the organisation of matter: 1) fusion and division, 2) network formation, and 3) pulse and rhythm. In the first, cell propagation is developed through the generative process of fusion and division. In the second, the cells generate networks to form much larger colonies, like the growth from myoblasts to myotubes in the experiment. In the third, the cells show periodic movement like cardiac functions as a core of their life force: pulse (periodic beat) and rhythm (the pattern of sounds), which are similar to the spontaneous twitching of the myotubes that were observed in the experiment. I explore these three life-like behaviours in sub-chapters 3-2, 3-3, and 3-4.

My practice in this research involves interdisciplinary explorations between natural and artificial matter focused on these three life-like behaviours, expressed through sonic and visual anthropomorphism.[54] Other sound artists have explored living materials to harness their sound expression. Some sound art projects involve the biological processes of (semi-)living entities as co-makers and co-authors in the compositional process. *CellF* (2015) by Guy Ben-Ary, an artist and

[54] See pp.19–20 in Chapter 1 for a description of 'anthropomorphism'.

researcher at SymbioticA, is an attempt to create a musical performance with a living neural network that is created from the artist's cells (Ban-Ary et al. 2015；Moore et al. 2016). It features a biological synthesiser that consists of a neural network and a series of analogue circuits. The core of the system is autonomously controlled by neural networks that are artificially grown in a petri dish. The neural networks were originally made from skin cells taken from the artist's arm: the skin cells are transformed into neural stem cells by induced pluripotent stem (iPS) cell technology. This synthesiser can 'play' musical improvisations in interactions with human players of musical instruments. The sound created by the human players gives electrical stimuli to the neural networks, and the neural signals control the custom-built analogue modular synthesisers to generate sound in real time.

Another example of biocomputer music was developed by Eduardo Miranda, head of the Interdisciplinary Centre for Computer Music Research (ICCMR) at Plymouth University (Braund and Miranda 2014; Miranda, Adamatzky, and Jones 2011; Miranda 2017). Miranda developed one of the approaches of unconventional computing: a biological computation system for music using Physarum polycephalum, more commonly known as slime mould. The system creates a 'conversation' between slime mould and the piano. When the artist plays the piano, the slime mould responds by changing its shape in accordance with the piano keys. The movement of the slime mould generates electrical energy, which Miranda's system transforms into sound. Miranda's projects *Biocomputer Music* (2015) and *Biocomputer Rhythms* (2016) explore the potential sound expression of this biocomputer system.

In both Ben-Ary and Miranda's projects, humans and living materials co-create and perform music through their interaction. By contrast, my own practice is focussed on the generative processes of non-living materials. Although there is always a collaborative relationship between an artist and their materials in the composition process, my practice submitted in the PhD portfolio is distinctive in that it engages with sonic and visual anthropomorphism and involves co-composition between natural and artificial matter which is focused on the life-like behaviours of non-living materials that resemble biologically living ones.

3-2. Fusion and Division

In 2017, I created a set of two contrasting pieces called *transition*. *transition* is an investigation into the notion of time and space in transformations between natural and artificial matter. The idea behind this project was to explore our current environment, which is surrounded by matter that is merged between nature and artefacts. By crossing the boundary between these in an integrated expression, *transition* demonstrates new aesthetic qualities of sounds as the emergence of time and space. This project consists of two contrasting pieces, *[systemic]* and *[characteristic]*, which take opposite directions in the transition process between natural and artificial mechanisms to investigate the diversity and immensity of the central idea. The first piece, a sound installation *transition [systemic]*, is an exploration of ‘fusion and division’. The second piece, *transition [characteristic]*, is focused on ‘network formation’. This sub-chapter describes *transition [systemic]*, and the next sub-chapter describes *transition [characteristic]*.

transition [systemic]

Description

transition [systemic] (2017)[55] is dedicated to the conversion of natural mechanisms into artificial ones. It comprises a series of photograms that mimic a primitive life cycle. The photograms are the optical trails of primitive, life-like behaviour, such as division and fusion, generated through chemical reactions. The first image shows the birth of 'chemical cells',[56] while the final one shows the collapse of the developed cells through evolution. The behaviours of the cells are transferred to the recording surface of optical media in photogram form. This piece explores the diversity of autonomous expression created through natural and artificial mechanisms.

[55] The piece *transition [systemic]* was presented at the final exhibition at Tokyo Wonder Site Shibuya – *Shibuyajizai: Infinity, or Self-Territory* – organised by Tokyo Wonder Site from 29 July to 17 September 2017. (The organisation was re-named 'Tokyo Arts and Space' in October 2017.)

[56] My own use of the term 'chemical cells' refers to cell-like objects artificially created by chemical materials, which show life-like behaviours.

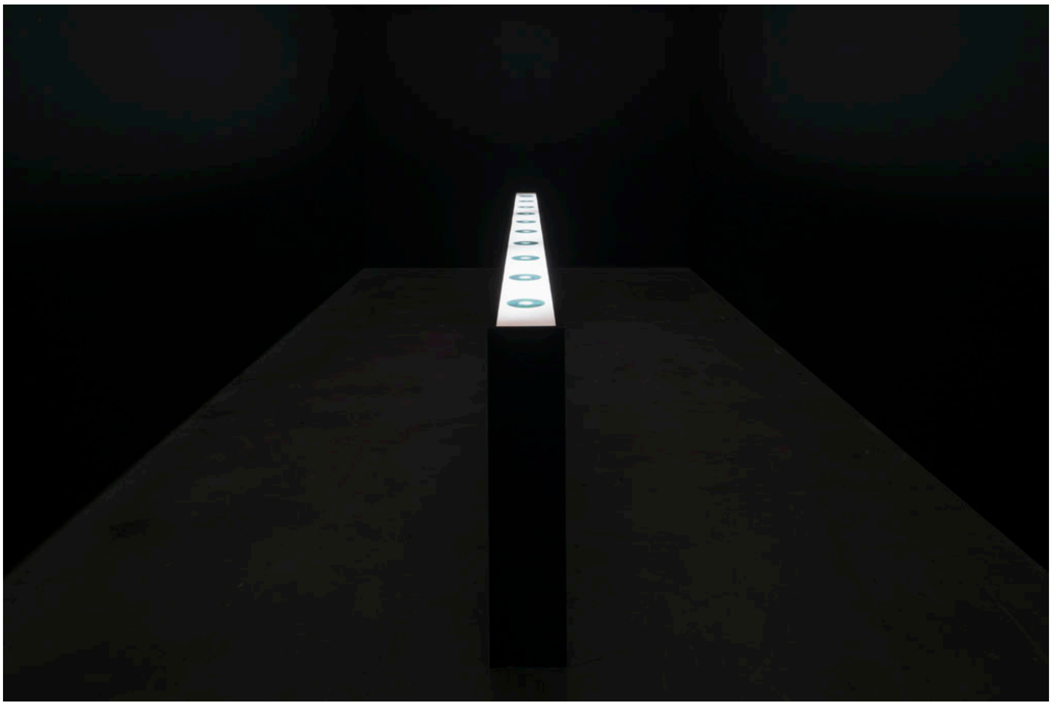

Figure 5 *transition [systemic]*, Mari Ohno (2017). Photo: Ken Kato. Photo courtesy: Tokyo Arts and Space.

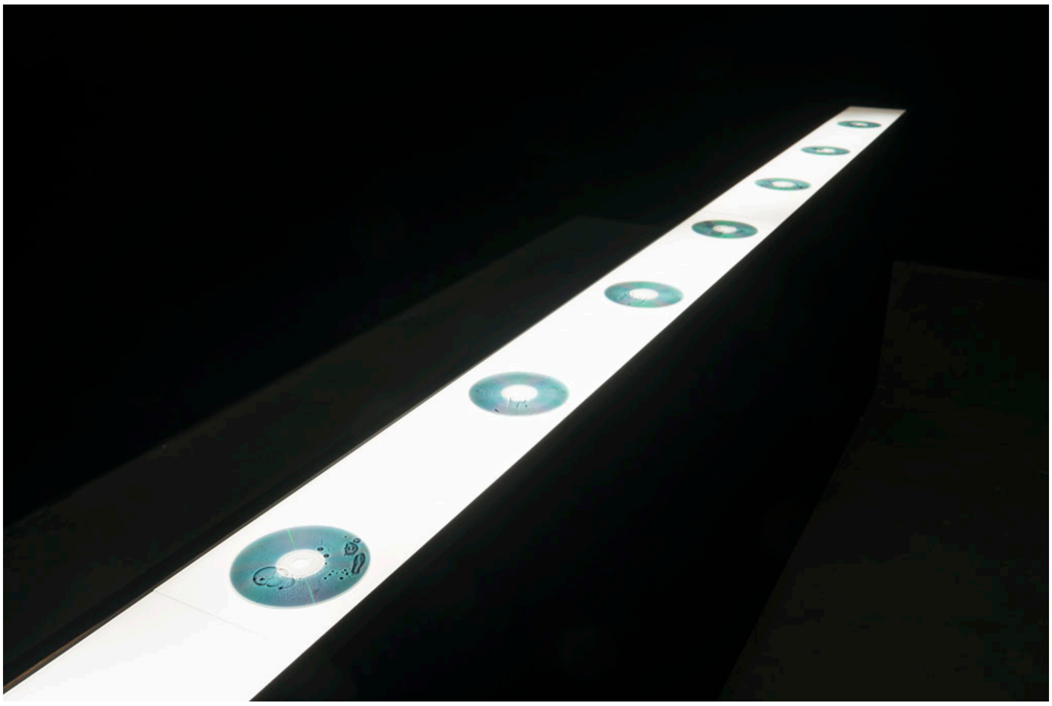

Figure 6 *transition [systemic]*, Mari Ohno (2017). Photo: Ken Kato. Photo courtesy: Tokyo Arts and Space.

[Details]

Title: *transition [systemic]*

Year: 2017

Materials: screen-printed photograms on compact discs

Size: W 200 mm × L 400 mm × H 900 mm

Context

transition [systemic] began from my interest in the vitalism[57] of chemical reactions and fluid motion. I focused on and explored the movement of fusion and division as a life-like behaviour, inspired by a recent research trend in artificial life, called protocells. Protocells are designed to be an intermediate state of bodies between living and non-living. They are composed of non-living chemical materials and mimic some biological properties of life. In my interpretation, the chemical behaviour gives us a sense of vitalism; the idea is that both living/non-living matter should exhibit creative force from their fundamental decision making and/or behaviour. This project is an exploration of what vitalism is made of. The simple shape of protocells gives us a realisation of the complex mechanisms of natural life through their autonomous chemical reactions.

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[57] See pp.20–22 in Chapter 1 for a discussion of my own use of the term 'vitalism'.

Before creating *transition [systemic]*, I created a short film study titled *energy in motion* (2016),[58] a bio-sonic exploration of vitalism through life-like behaviours of chemical cells. This piece demonstrates the vital energy created through momentary changes in the chemical reactions on a microscopic scale. In this piece, the microscopic artificial cells drawn by chemical materials show some autonomous behaviours that resemble living cells, such as fusion and division. The cell's behaviours, including shapes, movements, and speed, are automatically analysed and transformed into generative sounds via computation. In other words, the artist composes the visual elements of the cells whose behaviours generate sounds, and the cells themselves 'compose' others. These generative sounds of the cell's behaviours are co-performed with the artist's sonic and visual composition for this film. Thus, this sonic and visual outcome is a co-composition by both the artist's creative intention and the autonomous behaviours of the chemical cells. Through a series of chemical reactions, the piece shows the diversity and complexity of the cells' behaviours.

[58] Mari Ohno *energy in motion* (2016), film, 2 min 12 sec.

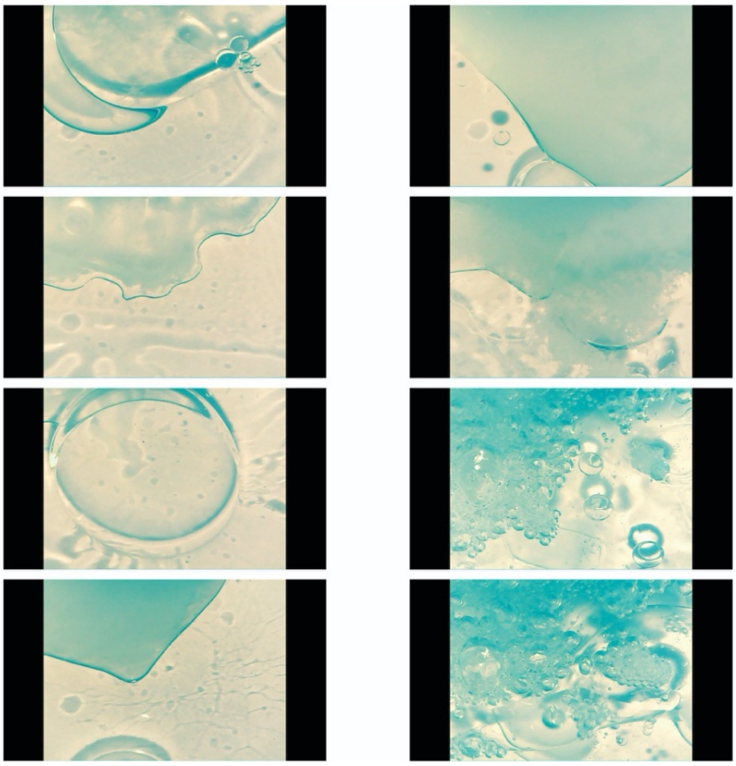

Figure 7 The stills from *energy in motion*, Mari Ohno (2016).

For more details of this study, see the 2-1-1. written documentation and 2-1-2. video documentation in the Appendices, which are in the folder labelled *2-1. energy in motion* in the folder of *Appendix 2* on the attached USB memory stick.

In *energy in motion*, I referred to the method of 'DIY protocells' proposed by Hanczyc, to mimic the chemical behaviour of fusion and division in the microscopic drawing (Hanczyc 2014). He suggested creating simple protocells by using substitutes which are not high-purity reagents for laboratory use. He referred to an early model of simple protocells, called the Bütschli dynamic droplet system, that was developed by Bütschli (Bütschli 1982). That model contains an artificial amoeba that represents a primitive life. According to Hanczyc's research, such a simple physico-chemical system can be made by means of mundane materials: potash and olive oil, whose reaction when combined causes saponification.[59] These non-living materials demonstrate the qualities of artificial life. I was inspired by Hanczyc's method and used only easily available materials for home use, not the reagents for laboratory use.

My motivation to engage with the next piece *transition [systemic]* is driven by my interest in the 'life cycle' of the chemical cells. The creative outcome of the chemical reactions is continuously changing through a chain of reactions caused by the cell's own autonomous behaviour. Namely, the chemical behaviour of fusion and division is not always the same and it encourages 'growth' and/or 'evolution' through the accumulation of behaviour within their 'span of life'. Thus, this repetition of behaviour with the same regularity throughout its life makes the matter appear more life-like to us. I wondered whether this life-like development of the cells is motivated by the 'intention' of the non-living matter itself whether the active quality of matter constitutes one of the elements of vitalism. In my previous film piece *energy in motion*, I focused on the momentary changes in the chemical behaviour and attempted to show via sonification the vitalism of non-living matter emerging through the autonomous behaviour in every moment which occurs and changes instantly. Sonification can simplify the perception of a complex mechanism of nature by responding only to specific features selected by the artist. Such a simplification can also hide the pure order and disorder[60] of nature. This piece led me to establish a further research objective: creating a new sound expression with the chemical cells as a co-author and co-maker by entrusting a temporal and spatial 'sense' of the creation to the materials and

[59] According to the *Oxford English Dictionary*, 'saponification' is defined as: 'the process of saponifying; the decomposition of a fat by the addition of an alkali which combines with its fatty acids to form a soap, the remaining constituent, glycerine, being consequently liberated' (OED Online 2019d).

[60] See pp.21–22 in Chapter 1 for a discussion of my own use of the term 'order and disorder'.

leaving a blank space for the interpretation and intention of the creative outcome by the materials themselves, rather than selecting a particular moment by the artist's intention. In *transition [systemic]*, I established another approach of co-composition, focused on the life-like behaviour of fusion and division, by incorporating the temporal and spatial sense of materials beyond human's decision making and behaviour in the post-anthropocentric[61] context.

The sound installation, *transition [systemic]*, is inspired by Kim Cascone's 'aesthetics of failure' (2000). Cascone argues that the unexpected errors created through the deconstructive use of digital technologies have new aesthetic value. Nicholas Negroponte had insisted in a 1998 article in *Wired* that 'the Digital Revolution is over', as digital technology was already regarded as one of the ordinary and essential things in our daily lives and was no longer revolutionary (Negroponte 1998). Referring to Negroponte's words, Cascone points to the emergent culture in digital music since the 1990s, what he calls the 'post-digital' tendency. Most technologies are designed and controlled to prevent errors, and humans should not experience them in normal use. However, many composers have actively used errors as the core of their compositions, exploring their possibilities as new ways of sound expression. Cascone states that 'the medium is no longer the message; rather, specific tools themselves have become the message' (Cascone 2000, 12). For some examples of aesthetic 'failure' in digital music, Cascone offers the following:

> The 'post-digital' aesthetic was developed in part as a result of the immersive experience of working in environments suffused with digital technology: computer fans whirring, laser printers churning out documents, the sonification of user-interfaces, and the muffled noise of

[61] See pp.18–19 in Chapter 1 for a discussion of my own use of the term 'post-anthropocentric'.

> hard drives. But more specifically, it is from the 'failure' of digital technology that this new work has emerged: glitches, bugs, application errors, system crashes, clipping, aliasing, distortion, quantization noise, and even the noise floor of computer sound cards are the raw materials composers seek to incorporate into their music. (Cascone 2000, 13)

Since the world's first CD was released in 1982, many artists have composed music for CD by turning the CD into an instrument, not a mere recording medium, exploring the characteristics of the CD and its playback mechanisms. Glitch is one post-digital technique for creating microscopic noise by intentionally causing errors in CD systems, such as modifications on the surface of a CD and modifications of the CD player itself. This technique can produce novel sound works composed of the glitching and skipping sounds, which is only feasible by using the CD system. Representative artists in this approach are Oval, Yasunao Tone, and Nicolas Collins (Stuart 2003).

This post-digital aesthetic approach can be regarded as connected to post-anthropocentric ways of composition. Although the post-digital approach is an exploration of digital technology focused on the systemic characteristics themselves, it can also be described as a co-composition between humans and technologies. It is similar to how the compositional process entrusts autonomous behaviours of non-living matter. In *transition [systemic]*, I used CDs as materials, inspired by Cascone's philosophy, to explore the temporal and spatial attributes of chemical cells and CDs as imperceptible sonic and visual components and allow them as a creative intention within the process of co-composition between natural and artificial materials. This piece is a conceptual work to show the co-composed visual appearance on our perceptible level, rather than an auditory expression like glitch. The microscopic trails of the autonomous behaviour of the chemical cells are captured by the exposure of light as photograms. These photograms of the cells are transferred onto the recording surface of the

CDs; the CD is one of the representative media whose data is also written and read by light. The photographic trails of the cells, lasting a few seconds, are visible on the CDs with the duration of 74 minutes on a medium approximately 120 mm in diameter. The integrated artefacts may be mechanically played through CD systems. This artificial system of an optical medium may cause errors by the naturally generated trails of the chemical cells. In a gallery space, the audience can look at a series of ten photograms screen-printed on CDs, which imitate a minimal life cycle, from birth to death. The photogram is an ideal medium with which to preserve temporal reactions of the cells that humans cannot perceive at the same time as a series of processes. Capturing the light and shadow of objects simultaneously means 'preserving' the objects at that moment. This integrated matter looks like artificial 'fossils' on the digital media, which can be transformed into sounds as non-material elements.

Process

During the process of making the piece, I experimented with a series of alternative photographic processes to capture the images of the cells. The trails of the cells were drawn by fluidic movements which are generated through chemical reactions. Definitions of 'alternative photographic processes' are widely discussed, with various interpretations by some organisations, including AlternativePhotography.com (website), London Alternative Photography Collective, and Dutch Alternative Photography, and with no agreed consensus (AlternativePhotography 2015). My own use of this term refers to any cameraless historical and analogue process that can be combined with or without digital ones with an interdisciplinary perspective, either hand-printed directly onto light-sensitive materials with traditional techniques, or directly printed on light-sensitive materials in a camera. Among the examples are cyanotypes,[62] photograms,[63] chemigrams,[64] anthotypes,[65] and chemograms.[66] Figure 8 shows my studies of these alternative photographic processes. Modern artists reconsider alternative photographic processes and combine them with methods of standard digital printing as new techniques, in order to explore new aesthetic values. In his book *Alternative Photographic Processes: Crafting Handmade Images* (2015), Brandy Wilks suggests 'ALTERNATIVE ways to combine all aspects of photography and printmaking' in analogue and digital techniques, such as 'holding a piece of scratched glass in front of your lens, to using scanners as cameras, or using digital positives with collodion plates' (Wilks 2015, xi). I thought that such an

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[62] A cyanotype, also known as Blueprint, Sun print, Ferroprussiate print, and Iron print, was invented by Sir John Herschel in 1842 (Fabbri and Fabbri 2006). This process uses the light-sensitive materials coated with the mixed solution of Potassium ferricyanide and Ferric ammonium citrate. The photographic images are made by exposing under sunlight or UV light and developing with running water.

[63] A description of a 'photogram' is discussed on pp.94–95 in this sub-chapter.

[64] A chemigram is a photograph whose image is created by painting with chemicals onto a light-sensitive material in a darkroom and it is exposed to light.

[65] An anthotype process uses natural pigments, extracted from such as plants, flowers, vegetables, and others. The light-sensitive materials are made by coating these natural pigments, and the photographic images are developed by the action of sunlight. The exposure of sunlight needs for hours to weeks, depending on the pigments.

[66] A chemogram is a photograph made through two steps; first, a photographic image is enlarged into a photographic paper and processed in a darkroom. Once the image is processed at a preferred level, the photographic paper is selectively disrupted by using chemicals used in photographic processes, such as fixer and developer, with light exposure. These processes can be repeated to make the final image.

unconventional use of traditional techniques would make it possible to directly capture the fluidic trails of the cells in real time within the photographic process.

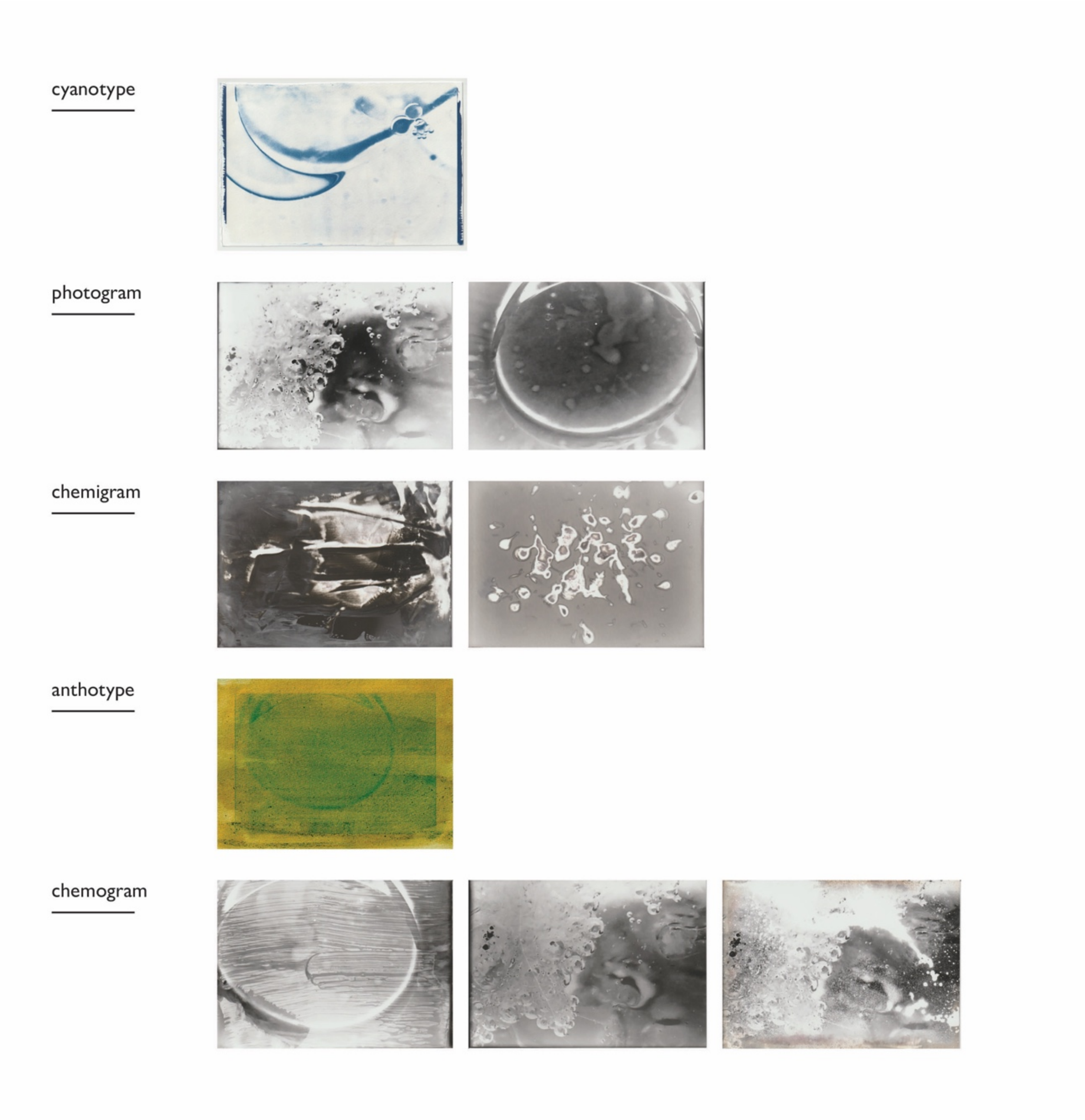

Figure 8 My studies of alternative photographic processes, Mari Ohno (2017).

After some photographic experiments, I was interested in photograms, which can capture the images of objects as essentially light and shadow, even for the trails of fluidic movements of subtle moments. A photogram is a photograph taken in a dark room without a camera, made by placing objects onto a light-sensitive material, such as a photographic paper and film, and then exposing it to light. The exposed material is developed and fixed in a standard way. The photogram image is always negative, as the object covers the light-sensitive material and where the object is placed is not exposed to light. The tone of lightness/darkness of the photograph depends on the transparency of the object itself, the strength and duration of the light, and the distance between the object and the light source. This photographic process is co-operatively created by natural reactions and artificial materials and techniques in an analogue way.

In terms of the co-composition between natural and artificial matter in photographic processes, the photographic images can be captured not only by a camera, but also by other materials and processes that are not properly used in conventional photography. Some scientific projects can be regarded as unconventional approaches to photographic processes, exploring the photographic images made by the order of nature. One example is the *Bactograph*, developed by two researchers Brian Landry and Ravi Sheth at Jeff Tabor's lab at Rice University (Bactograph, n.d.). This is an elementary kit for creating bacterial photographs for young scientists, allowing them to work in their own environments, such as high schools and museums. The bacterial photographs are created with genetically modified bacteria that change their colour by reacting with light. A petri dish that contains the bacteria is attached to a transparency of the image like a negative, and the photographic image is developed by culturing the bacteria with a light source in an incubator.

Another example is the project of bacterial handprints by Tasha Sturm, who is an expert in microbiology and immunology. She explores the immensity and diversity of bacteria, yeast, and moulds in our environment. Her project is a bacterial handprint of her eight-year-old son, whose image is captured by the culture of bacteria that were on his hands after he came back from playing outside (Fessenden 2015). The bacteria were transferred to agar plates by putting his hands onto them and were incubated for a few days. The shape and colour of the bacterial colonies that grew indicate the variety of the bacterial species, such as *Bacillus* spp., *Clostridium* spp., *Staphylococcus* spp., and *Micrococcus* spp.; those organisms are commonly found on our bodies (Sturm 2018). This project of handprints is actually not aimed at taking a photograph, but it can be described as a 'bacterial photograph'. This photographic image is changing all the time as it grows through the interaction with the surrounded environment as living matter, which is not stable and permanent.

In my piece, I combined microscopic chemical drawing with an alternative photographic process. I created a trigger for the autonomous behaviour of the cells generated by chemical reactions in almost the same way as my previous film study *energy in motion*. The only difference is that I integrated this drawing process with light-sensitive materials in a dark room to be exposed to light for a few seconds. In this way, I made hundreds of photograms of the trail of the cells in a series of fluid motions, and then chose ten examples to show as an otherworldly story of a primitive life cycle from birth to death. These photograms were screen-printed onto CDs. For more details, see the 2-2-1. written documentation in the Appendices, which is in the folder labelled *2-2. transition [systemic]* in the folder of *Appendix 2* on the attached USB memory stick.

transition [systemic] can be described as the materialised media of sounds, created through the conversion process from natural mechanisms to artificial ones. The natural growing process of the chemical cells is traced through photographic processes and decoded by artificial mechanical processes of CD systems for a sonic and visual output. It represents the unexpected reactions by chance, which happen only once at a certain moment: between order and disorder in nature. Some artists have treated various natural materials as sound media through different approaches, to explore the order and disorder in the original materials.

One such example is the sound installation *Years* (2011) by Bartholomäus Traubeck (Traubeck, n.d.). *Years* exhibits the sound of a 'vinyl record' made from a slice of the trunk of a tree. The sliced tree trunk is played by a record player modified with pre-programmed software to analyse the data of the growth rings; the software analyses the trunk in terms of its strength, thickness, and rate of growth, and then generates piano music based on the data it extracts. Although the hardware and software setup of the record player is the same for each slice of tree trunk, the generated music varies depending on the tree analysed. In Traubeck's his own words:

> I created this work because I wanted to find a way to make musical compositions out of patterns occurring in nature over longer periods of time.
>
> Wood seemed the best material for this for two reasons. First of all the material is its own record of growth and this fact is easily understandable in a visual way. Secondly there is something of a visual analogy between the single groove of a record and the multiple rings

> on a slice of wood. This reflects the archetypical medium for musical storage, the vinyl disc. (Traubeck; Sakamoto et al. 2012, 122)

Another example is the kinetic sound sculpture *(Un)Measurements* (2016) by Gil Delindro (Delindro, n.d.). This piece is comprised of a system that plays the sound of a decayed tree inhabited by a lot of fungi and larvae. Although the decayed parts of the tree were carved, bacteria still thrived to 'construct' the shape and structure of the tree created by its decay. The acoustic characteristics of the tree change due to the decay process caused by the bacteria and insects inhabiting the tree. A large tree branch rotates like a record player, and the sound is amplified by five microphones attached at fixed reading positions. The microphones trace the surface of the tree like the needle of a record player. Although the rotation period is always the same, the sound is not repeated as the orbit constantly varies; the surface of the rotating wood is not stable, and the reading positions of the microphones are changing all the time. Delindro describes that the sound in this piece is generated by 'a polyrhythmic interplay between order and chaos in a constant transient orbit' (Delindro, n.d.). He considers the unstable path taken in rotation in this piece as a key element to realising the order and chaos behind nature. In his words:

> Consider a mechanic rotation, like the motor of a car: it has a fixed cycle but no rotation is exactly equal to its previous, there is a direction but total repetition is impossible, an external signal contaminates slowly but always. Such is the nature of all matter, a cyclic being but never a static one. (Delindro, n.d.)

Both of these pieces use wood as their material, but this is just a coincidence. More importantly, these pieces are similar in that their sounds are expanded and amplified by entrusting to the order and disorder of the natural materials. In addition, they have in common a media player that plays the medium by mechanical rotation of the playback system. Similarly, these pieces use a certain cycle of mechanical rotation that is artificially set to play natural materials as media.

In comparison, my piece differs in the following two ways. Firstly, my piece is an exploration of the life-like behaviour of the chemical cells, which are not naturally born. However, this artificial life also represents the unexpected and surprising creative outcome of chance through a series of reactions, like natural materials. In the compositional process, the accumulation of the reactions encourages growth and/or evolution as long as it naturally continues. Secondly, *transition [systemic]* shows the autonomous transformation from visual to sonic elements, triggered by the life-like behaviour of fusion and division. The overall appearance is the visual accumulation of the cells' movements by fusion and division captured by photograms as time passes, and it may be played as sound through the mechanical systems of a media player. Although the artist's intervention is present at every stage of the compositional process as long as this is an art piece, this systemic conversion process from visual to sonic elements does not include the artist's intervention; as the photograms are naturally made by light and shadow, and CD systems mechanically read the visual data, the outcome is autonomously preserved and transformed from nature to artefacts. Based on the above two features, my piece exploring the life-like behaviour of fusion and division can be considered a conceptual piece that attempts to incorporate the order and disorder of nature into the co-composition by entrusting to a temporal and spatial sense of natural materials as the vitalism of matter.

3-3. Network Formation

transition [characteristic] is a contrasting piece to *transition [systemic]*. It is an aesthetic exploration of 'network formation'.

transition [characteristic]

Description

transition [characteristic] (2017)[67] represents the conversion of artificial mechanisms into natural ones. This piece is a mechanical system that creates acoustic reactions through salt crystallisation. Salt is an essential mineral to life and cannot be produced by living organisms. Some salt may be the residual substance of brine or ancient seas, and some may have arrived from outer space. Although salt itself is non-living matter, it shows life-like behaviour in the crystallisation process – it creates networks to form its structure. The sounds in this piece are triggered by the mechanical system, while the texture changes depending on the crystallisation process over the few months of the exhibition, at a speed that eludes human perception.

[67] *transition [characteristic]* was also presented at the same exhibition as *transition [systemic]*, from 29 July to 17 September 2017, at the final exhibition at Tokyo Wonder Site Shibuya – *Shibuyajizai: Infinity, or Self-Territor*y – organised by Tokyo Wonder Site, where was re-named 'Tokyo Arts and Space' after this exhibition.

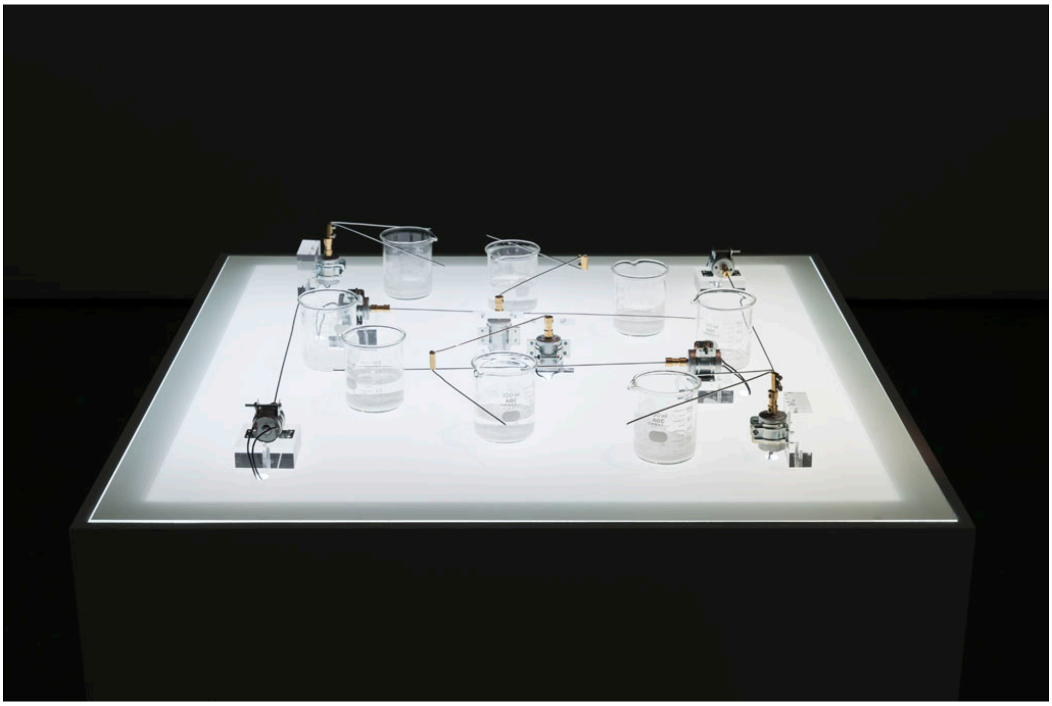

Figure 9 *transition [characteristic]*, Mari Ohno (2017). Photo: Ken Kato. Photo courtesy: Tokyo Arts and Space.

Figure 10 *transition [characteristic]*, Mari Ohno (2017). Photo: Ken Kato. Photo courtesy: Tokyo Arts and Space.

[Details]

Title: *transition [characteristic]*

Year: 2017

Materials: salt, water, beakers, aluminium, acrylic, motors

Size: W 700 mm × L 700 mm × H 700 mm

Context

transition [characteristic] is motivated by my interest in the creative process of network formation, and the aesthetic qualities of symmetry and patterns in nature. This mechanism of network formation can be observed not only in the cells of living bodies such as humans and animals, but also in other less sophisticated living and non-living materials, such as plants, fungi, and minerals, including trees, leaves, slime mould, crystals, snowflakes, spider webs, bees' honeycomb, ant colonies, and others. The growing processes of such ramified structures can be interpreted as life-like behaviour.

The network formation of natural materials has been explored by artists and scientists from different perspectives. One such example is a constellation of three-dimensional sculptures, titled *Webs on At-tent(s)ion* (2018), by the Argentinian artist Tomás Saraceno (Studio Tomás Saraceno 2019). *Webs on At-tent(s)ion* shows a floating landscape composed of hybrid spiderwebs interwoven by spiders of unrelated interspecies. The individual threads of the spiderwebs form a speculative architecture through the collisions of various sensory imaginations between the spiders. This architecture also provides the spiders themselves with a home. This creative landscape changes through the entanglements and connections between the spiders, as well as those between humans and non-humans, in an ecosystem. In this installation, each spider's imaginative movement affects the movement of the others. The spiders sense the vibrations of the spiderwebs through their filaments, which extends their sensory world like additional ears, eyes, and mouths. Some of these vibrations are amplified by specific microphones, which allows the audience to hear the rhythm of the interspecies ensemble like a musical instrument.

A scientific project led by Andrew Adamatzky creates new motorway networks based on the urban areas of fourteen countries using the network formations of Physarum polycephalum (slime mould) (Adamatzky et al. 2013). This project aims to improve the efficiency of urban transportation systems by applying the network behaviours originally formed through the mould's search for food (oatmeal) in dark, moist environments. Adamatzky arranged the food so that the slime mould could develop protoplasmic networks, and compared these created networks with the motorway networks of the following countries: Australia, Africa, Belgium, Brazil, Canada, China, Germany, Italy, Malaysia, Mexico, the Netherlands, Spain, the UK, and the USA. Similarly, another research group led by Toshiyuki Nakagaki created in 2010 a rail network in Tokyo based on slime mould network development (Tero et al. 2015).

In *transition [characteristic]*, I focused on the network formation of the inorganic minerals found in seawater, as an essential matter for supporting life. These minerals cannot be produced within our bodies. The salt is typically contained in seawater, and the total amount of seawater is estimated to cover nearly 71 percent (or 361 million square kilometres) of the surface of the earth (Hancock and Skinner 2000). The sea salt is made of six major ions: chloride, sodium, sulfate, magnesium, calcium, and potassium. The other smaller amounts of dissolved substances in seawater are made up of five major constituents: inorganic carbon, bromide, boron, strontium, and fluoride. Geologically, the earth is estimated to have been formed approximately 4.54 Ga (4.54 billion years) ago, and the atmosphere and oceans were developed during the early geologic history of the planet (Dalrymple 2001). However, over such an immense history, seawater has circulated around the earth at a rate of once every 2,000 years without any changes in its total amount and components (Sugita 2006, translated by the author). In this circulation, it has given birth to more than 30 million species of organisms on the earth. In my practice, I experiment with the crystallisation of minerals in seawater to explore the network formation of inorganic matter that is responsible for the appearance of organic matter.

In the beginning, I observed the structure and process of crystal formation of some types of sodium chloride (salt). Crystallisation is one of the ‘phase transitions’ which is the change of substance from a liquid, solution, or gas to a different state of matter (Yu and Reutzel-Edens 2003). Crystalline solids, or crystals, have distinctive internal structures in which atoms, molecules, or ions are arranged in an ordered pattern. The process of crystal formation differs depending on the conditions of its surrounding environment, such as temperature and pressure. These parameters affect the speed of formation, shape, structure, transparency, and strength of the crystals. Through a series of experiments, I found that I prefer especially sea salt for the aesthetic qualities of its structure, shapes, and colour. Figure 11 shows my study of crystal formation using some types of salt crystals. Strictly speaking, salt is a chemical compound formed by a neutralisation reaction, which refers to the chemical reaction of an acid with a base (Law 2017). Although different types of salts have different compositions (which correspond to their colour), all salts have similar crystallisation behaviours. However, I was interested in making crystals from sea salt, inspired by the hypothesis that some salt may be the residual substance of brine or ancient seas, or a substance arrived from outer space.

Figure 11 My experiment of crystal formation using sea salt, Himalayan pink salt, Celtic sea salt, and grey rock salt (2017). Photo: Mari Ohno.

In these experiments, I could create the static appearance of salt crystallisation, focusing on the aesthetic qualities of the structure, shapes, and colour. This outcome led me to the further idea to autonomously make instrumental sounds through the crystallisation process on a long-lasting timescale that humans cannot perceive. In *transition [characteristic]*, I created a sound installation whose sonic and visual expression is created through co-composition between the salt crystallisation naturally formed over a few months during the exhibition and the mechanical system that runs with stable intervals artificially created by the artist.

Process

Following my experiments in mineral crystallisation, it was important to think how to combine the crystals with materials to co-compose sound objects within an art work. Through the experiments with possible combinations of various materials in different shapes and sizes, such as glass, plastics, metal, wood, and fibres, I chose the combination of glass beakers and metal rods as instrumental materials to create an industrial and scientific appearance. Having selected my materials, I conducted further experiments with the relationship between the process of salt crystallisation and instrumental materials. To show the crystallisation process, the salt solution needs to be prepared first and allowed to evaporate to form crystals over time, through the physical transformation from liquid to solid. The sounds are made by contact between the glass beakers into which the solution is poured and metal rods while the solution is becoming dehydrated. Because of this, the pitch, sustain, and volume of the sound gradually change based on the condition of the crystals from wet to dry over the course of days. In addition, I needed to test glass beakers made by different manufacturers, as the sound depends on the density and thickness of the glass, and the ingredients of the beakers, even if they are the same size. Through experiments with combinations of types of beakers and the amount of water in them, I adjusted the sound qualities to a material combination that can systematically play musical scales in given intervals, when the state of the contained solution is liquid.

Consequently, I created a system in which sound is made by metal rods coming into contact with beakers whose acoustic characteristics are continuously changing due to the crystallisation process in the salt solution they contain. The installation consists of eight sound objects in four different shapes, constructed from a beaker and motor-mounted metal rod each. These objects are placed on well-designed positions to create a kinetic sound structure on top of a light table that improves the visibility of the salt crystals. The sound is made in two different ways: one is by striking the beakers with the metal rods, and the other one is by tickling the beakers by way of the rotation of metal rods powered by motors. The movement of the sound objects is controlled by four microcontrollers, which drive the motors according to pre-programmed intervals. The movements and intervals of the motors are arbitrarily programmed to never emit a sound at the same time. These elements have nothing to do with the crystallisation process directly. During the exhibition, the salt solution in the beakers becomes evaporated and turns into solid crystals. After the first solution is evaporated, an extra solution is added to the amount that was initially poured, over the period of the exhibition. In this way, the crystals keep forming and form a larger geometric structure whose acoustic reactions change slightly over the course of a few months. The objects co-compose a kinetic sound sculpture whose sound is continuously changing with the crystallisation process of salt over an imperceptible scale. For more details, see the 2-3-1. written documentation and 2-3-2. video documentation in the Appendices, which are in the folder labelled *2-3. transition [characteristic]* in the folder of *Appendix 2* on the attached USB memory stick.

After the exhibition of this piece, I had an opportunity to collaborate with Professor Anatoly Zayats, the head of the Photonics and Nanotechnology Group at King's College London. I was interested in the geometry of the periodic structure of crystals and its process of formation on a microscopic scale. Zayats specialises in the nano-optics of metamaterials, which are artificial substances that have properties not observed in matter from the natural world. For instance, plasmonic nanorods are small metal chips whose internal structure is well-engineered at the nanoscale (Kabashin et al. 2009). The internal unit elements are artificially designed at intervals smaller than the wavelength of electromagnetic waves. This structural design can affect the nanorods' electronic and magnetic characteristics, which may be applied to diverse materials that control light and sound signals, such as sensory detectors and optical disks. From our perspective, the rods exhibit sensitive light reflection, scattering, refraction, interference, and dispersion, and their opal-like colour fluctuates depending on the angle of perception. This visible phenomenon of light on the nanorods occurs by a surface plasmon polariton (SPR), which refers to a mixed state of polarisation and electromagnetic waves that travels on the surface of metals (Zayats, Smolyaninov, and Maradudin 2005). The vivid example of these effects is the colour of gold nanoparticles or nanostructures, which can be green, yellow, or red, depending on their size and shape, different from the colour of unstructured gold. My research at the laboratory of the Photonics and Nanotechnology Group was supported by Zayats and his colleagues (Drs Diane Roth, Pan Wang, and William Wardley). As a part of the ongoing process for further research in the above project, the following experiments were performed under his direction at King's College London.[68]

At Zayats's laboratory, I observed the geometric structure and crystallisation process of some materials, including sodium chloride (salt) and magnesium sulfate (commonly known as 'Epsom salt') on a microscopic scale. The following pictures show the formation of sea salt crystals, which is one

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[68] I did not require ethical clearance from King's College London as no biological systems or personal [data] were involved. The data were collected by me and will not be used by anyone else for any research purposes.

of the salts that I experimented with at the laboratory (Figure 12). The pictures are taken at ten-minute intervals, taken from a microscope at 20x magnification with polarised sheets during a time-lapse recording, capturing one frame every two seconds over the course of two and a half hours.

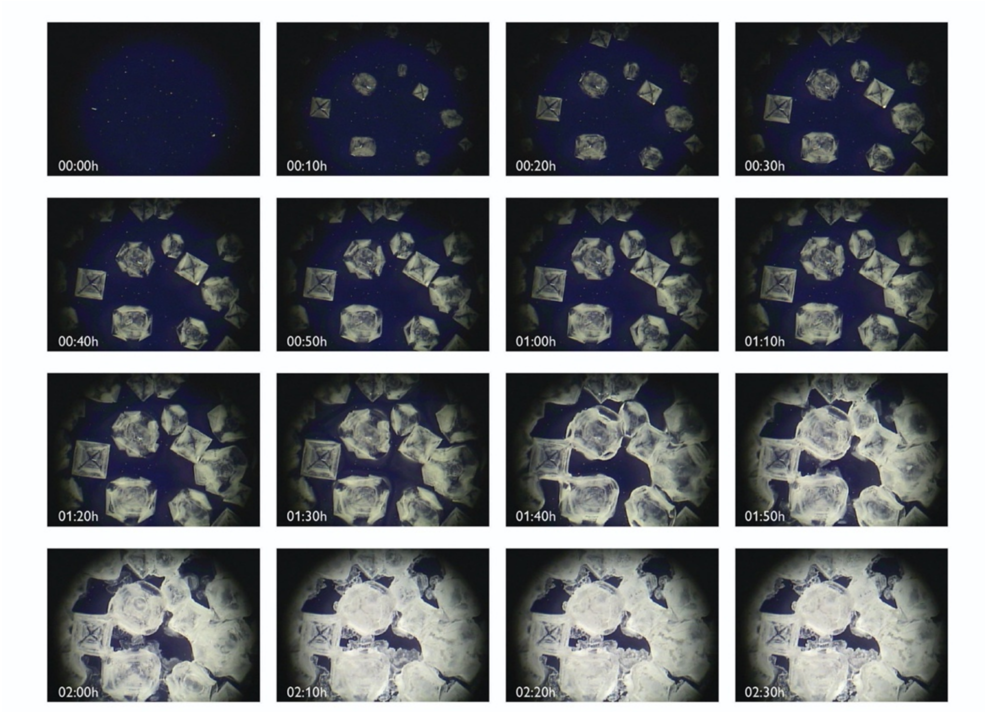

Figure 12 The formation of sea salt crystals, in my experiment at Professor Anatoly Zayats's Laboratory, at King's College London. Observed with 20x magnification reflection microscope through a polariser. Snapshots of the time-lapse recording by Mari Ohno (2018).

The movie of this time-lapse recording is in the Appendices; see the 1-1-2. time-lapse recording of sea salt crystals, in the folder labelled *1-1. lab experiment* in the folder of *Appendix 1* on the attached USB memory stick.

The above pictures show that salt crystals are constructed with minimal structures in the form of a cube, which is determined by the salt crystal lattice structure. The cubes are partly transparent and partly have white shining facets like pieces of ice. Most of the edges and angles of the cube structures are rounded due to the fact that the crystal formation is in progress within the solution. In the process of crystallisation, each cubic structure forms individually in a solution, and then they form a colony by connecting with each other.

In addition, the following pictures show the formation of magnesium sulfate crystals (Figure 13). The pictures were taken every five minutes, using a microscope at 20x magnification with polarised sheets during a time-lapse recording, capturing one frame every five seconds over the course of an hour.

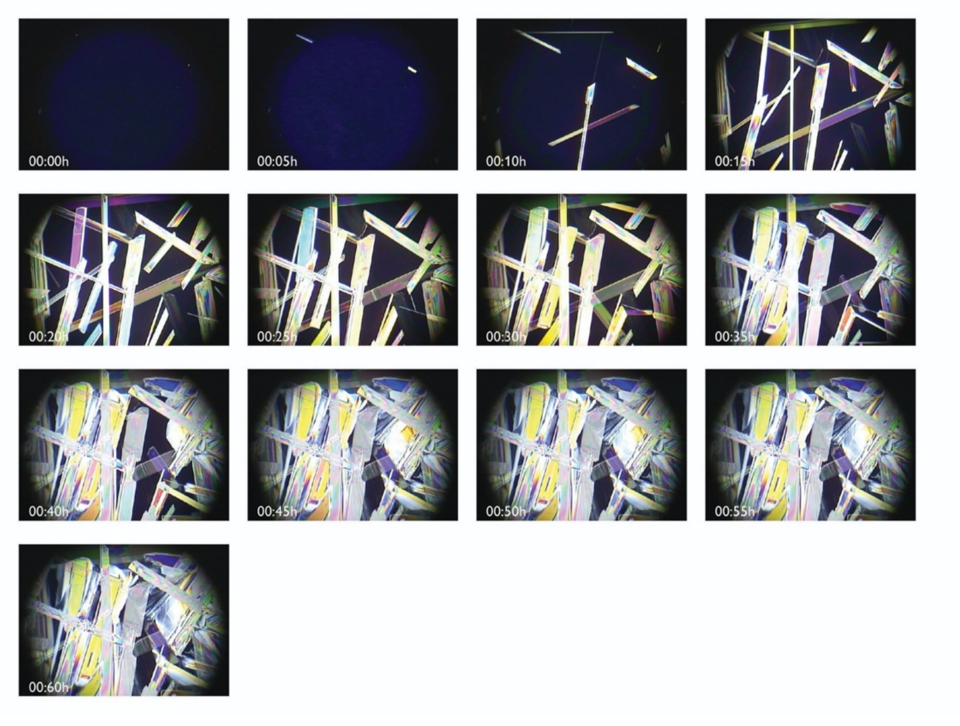

Figure 13 The formation of magnesium sulfate crystals, in my experiment at Professor Anatoly Zayats's Laboratory, at King's College London. Observed with 20x magnification reflection microscope through a polariser. Snapshots of the time-lapse recording by Mari Ohno (2018).

The movie of this time-lapse recording is in the Appendices; see the 1-1-3. time-lapse recording of magnesium sulfate crystals, in the folder labelled *1-1. lab experiment* in the folder of *Appendix 1* on the attached USB memory stick.

The crystal of magnesium sulfate forms monoclinic structures, whose crystallisation behaviours are different to the cubic structures of sodium chloride. These minerals show different processes of formation depending on their structure, and the crystals of magnesium sulfate form faster than sodium chloride.

After this observation, I became interested in artificially designing such periodic structures on a microscopic scale. I made five plasmonic nano gratings to observe natural light reactions made by metamaterials. The five gratings were designed to visualise the effect of sound waves of different frequencies – 400, 600, 800, 1,000, and 1,200 kHz – through the observation of the difference of a spectrum of reflected light. The internal structure of the grating (the separation between grooves) is designed as 400, 600, 800, 1,000, and 1,200 lines per 1 mm each on the surfaces of gold-coated glass chips. Thus, the frequency of the spatial separation of the grooves in the gratings corresponds to the frequency of the sound waves. Each of the gratings show unique light reactions, essentially by the reflection, scattering, and interference that occurs, depending on the frequency of the design of the surface. The following image is of the nano gratings that I made in collaboration with Zayats (Figure 14).

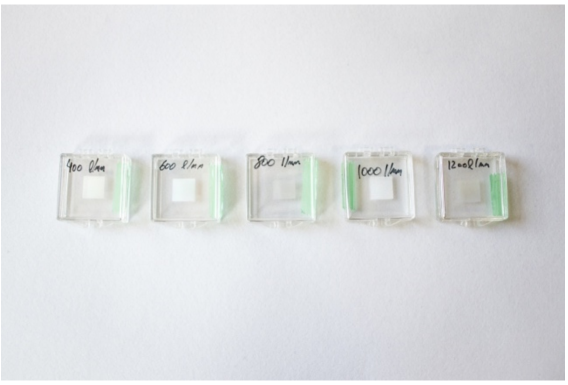

Figure 14 The nano gratings: grooves in gold-coated glass chips that I made, in collaboration with Professor Anatoly Zayats (2018). Photo: Mari Ohno.

The following images show the nano gratings on a microscopic scale, taken with a reflection optical microscope at 100x magnification with a white-light illumination (Figure 15). They show how a change in the frequency of the grooves changes our perception of light colour, despite the fact that all the gratings are made from the same materials. In *transition [characteristic]*, it could be similarly said that the difference in the size of the salt crystals in each beaker and the changes of the size by their growth over time were what resulted in changes in the sound components, although the materials are essentially the same. These results indicate that the change of the size of the structure using the same materials brings about a different sensory perception.

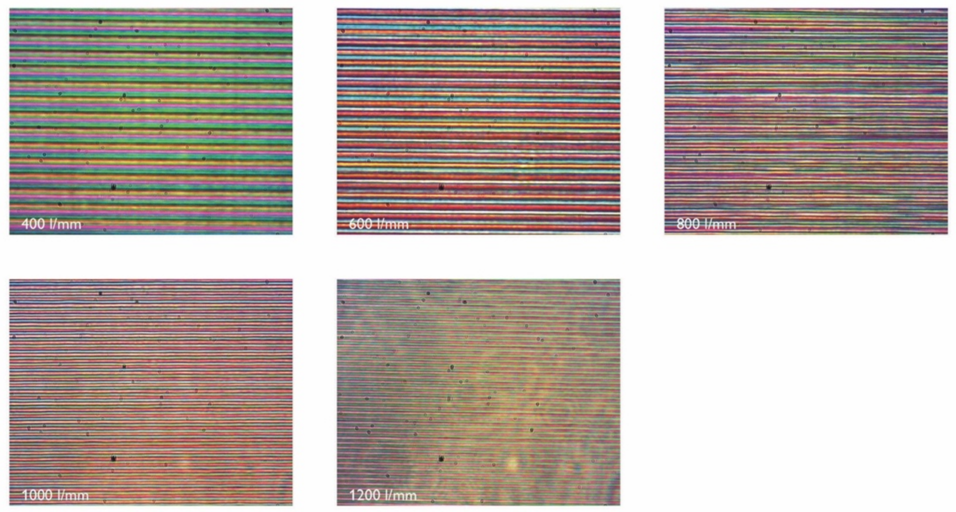

Figure 15 The images of the nano gratings recorded under white-light illumination. The frequency of the grooves in each grating is shown in respective images. In collaboration with Professor Anatoly Zayats. The pictures were taken by Mari Ohno at Professor Anatoly Zayats's Laboratory, at King's College London (2018).

This outcome indicates a more internally merged relationship between nature and artefacts. In contrast to salt crystallisation, the internal structure of nanochips on a microscopic scale is artificially periodic. However, what is visible to us are fluctuating sensitive light phenomena, that is, totally natural reactions. These made it possible for us to experience the non-acoustic 'sound' as a spectrum of light on the nano gratings, which corresponds with the effect of sound waves of inaudible frequencies. This experiment gave me a new inspiration to consider the internal creation of matter within our perception for sonic and visual expression in the post-anthropocentric[69] context.

[69] See pp.18–19 in Chapter 1 for a discussion of my own use of the term 'post-anthropocentric'.

In my experimental study *spectrum* (2019),[70] I created a sound installation to explore the visual appearance of inaudible sound. This piece is comprised of visual objects made of nano gratings whose internal structures express the sound waves of ultrasound in different frequencies, and a light source. It illustrates the aesthetic properties of visible spectra which are naturally created from the artificially designed objects of the nano gratings. Each grating shows various combinations of the spectral colour, depending on the internal structure of the gratings and the conditions of the light source. In this piece, the audience can 'hear' the inaudible sound waves through the co-composition between natural light reactions and artificially designed nanostructures.

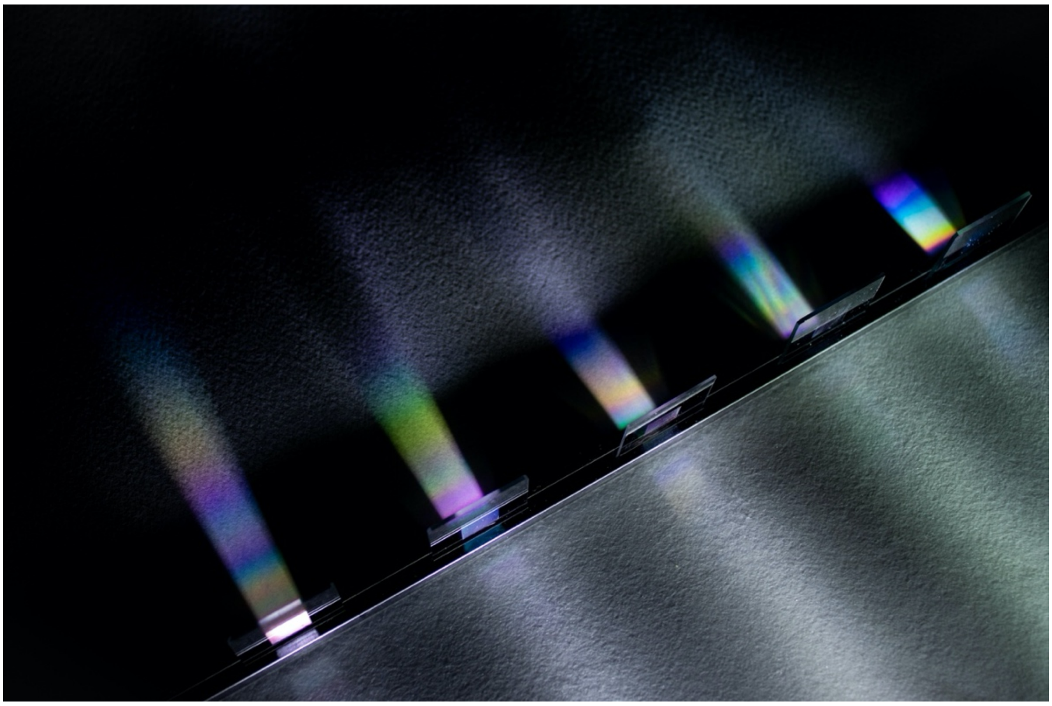

Figure 16 *spectrum*, Mari Ohno (2019). Photo: Mari Ohno.

[70] Mari Ohno *spectrum* (2019), sound installation, W 400mm × L550mm × H 50mm.

For more details, see the 2-4-1. written documentation in the Appendices, which is in the folder labelled *2-4. spectrum* in the folder of *Appendix 2* on the attached USB memory stick.

Self Evaluation

transition [characteristic] demonstrates another approach to co-composition, created through the conversion process from an artificial mechanism to a natural one. The whole system in this piece, including the environmental conditions, is artificially set, and the created artefact shows unexpected and surprising developments in a natural way over time. Some other artists have also proposed using salt crystals in their projects as critical reactions to social and environmental issues. For instance, the Israeli designer Erez Nevi Pana explores natural materials and processes to create furniture that does not use any animal-based materials, for sustainable outcomes in 'vegan design'. He uses natural substances such as branches, leaves, stones, textile scraps, and wooden scraps, with vegan glue made from plant fibres and wood resin for his projects (Dezeen 2018). He states:

> Practicing vegan design as another way of activism was a conscious choice, formed by the realisation that only a new conception of design and architecture could provide the means to reconstitute our self-centred culture and ensure our being in the world as we know it. (Dezeen 2019)

In one of Nevi Pana's projects *Salts* (2016), he explored the natural formation of salt crystals in the Dead Sea (Nevi Pana, n.d.). He created stools by combining plant-based materials and minerals. The stools were initially fabricated from wood, and then coated with thick layers of salt crystals by submerging them in the high-salinity water of the Dead Sea for several months. The outcome reveals unique shapes and structures generated by natural resources and processes, in collaboration with the designer.

Another example is the design project *Into(x) the Wild* (2018) by Livia Stacchini, which was exhibited at the Dutch Design Week 2018 in Eindhoven. *Into(x) the Wild* redefines 'nature' with interdisciplinary attention inspired by the context of the Anthropocene. This project is focused on Rosignano Solvay in Italy, particularly on its 'White Beaches', where there is one of the fifteen most polluted coasts of the Mediterranean Sea, as reported by the United Nations Environment Programme (UNEP) in 1999. The installation consists of five small sculptures of crystals comprised of sodium carbonate (soda) and salt crystals. Considering the influence of human activities, such as economic and social processes, that have damaged the natural environment, the piece demonstrates the paradox of human obsessions with hygiene in their daily living environment, in exchange for pollution in their external environment (Stacchini 2018).

Both of these projects by Nevi Pana and Stacchini demonstrate generative processes, shapes, and structures that are inspired by nature. However, differences with my project *transition [characteristic]* can be raised from the following two points. Firstly, my piece can be described as a musical instrument or sound object, focused on the acoustic properties of crystallisation and its expressive capabilities. It proposes a methodology for co-composing sonic and visual elements on imperceptible scales. The sonic and visual elements change slightly all the time, and they turn into an unexpected and surprising outcome. Secondly, my project focuses on mere aesthetic properties of the periodic structure of crystals, without taking a critical position towards social or environmental issues. The unique geometric shapes and structure give new textures to the prepared sonic and visual elements to co-compose integrated natural and artificial outcomes within the post-anthropocentric context.

3-4. Pulse and Rhythm

In 2017, I created a sound installation *moment*, inspired by human pulses, to explore 'pulse and rhythm'. This installation was organised by the Science Gallery London for the exhibition *Blood: Life Uncut* in October 2017. In developing the piece, I worked with Dr Manasi Nandi, a Senior Lecturer in Integrative Pharmacology at King's College London.

moment

Description

Pulses are biological reflections of our unperceivable physical and mental conditions. There are a variety of rhythms at any given moment in our bodies, depending on many factors, such as positions within the body, our activities, feelings, age, time of life, and our health conditions. The internal rhythmic clocks interact with each other through our blood circulatory system, like a traffic network. These biological rhythms may be described as the emergence of our humanity.

moment (2017)[71] is a sound installation which considers the principle of life and time, inspired by blood as the core unit of life force. This piece presents the immensity of unperceivable rhythms in our

[71] The piece *moment* was presented at the exhibition at the Science Gallery London – *Blood: Life Uncut* – organised by the Science Gallery London from 19–29 October 2017.

internal body, and the complexity of these interactions in the mechanism of life, at every moment. The aim of the project is to create new life-like artefacts triggered by our actual internal rhythms, in order to examine our perception and cognition to the boundary between natural and artificial life.

The piece is a series of instrumental kinetic objects that are controlled by human pulses recorded at different moments in our daily lives. All the kinetic objects are created in different shapes to represent different moments. Although the objects consist of inanimate materials, they demonstrate life-like movements which are triggered by pre-recorded our internal rhythms. These objects play instrumental sounds in real time, showing life-like movements, through the momentum that each asymmetric structure creates. The sonic and visual outcome is orchestrated through the interaction between the objects whose rhythms are continuously changing over time.

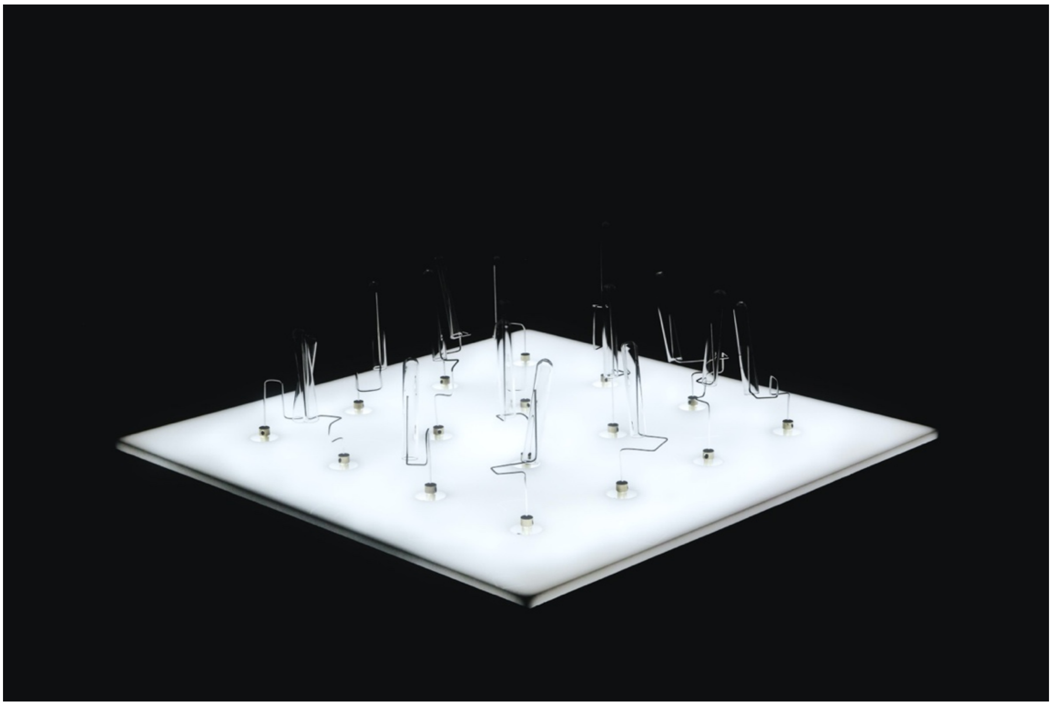

Figure 17 *moment*, Mari Ohno (2017). Photo: Mari Ohno.

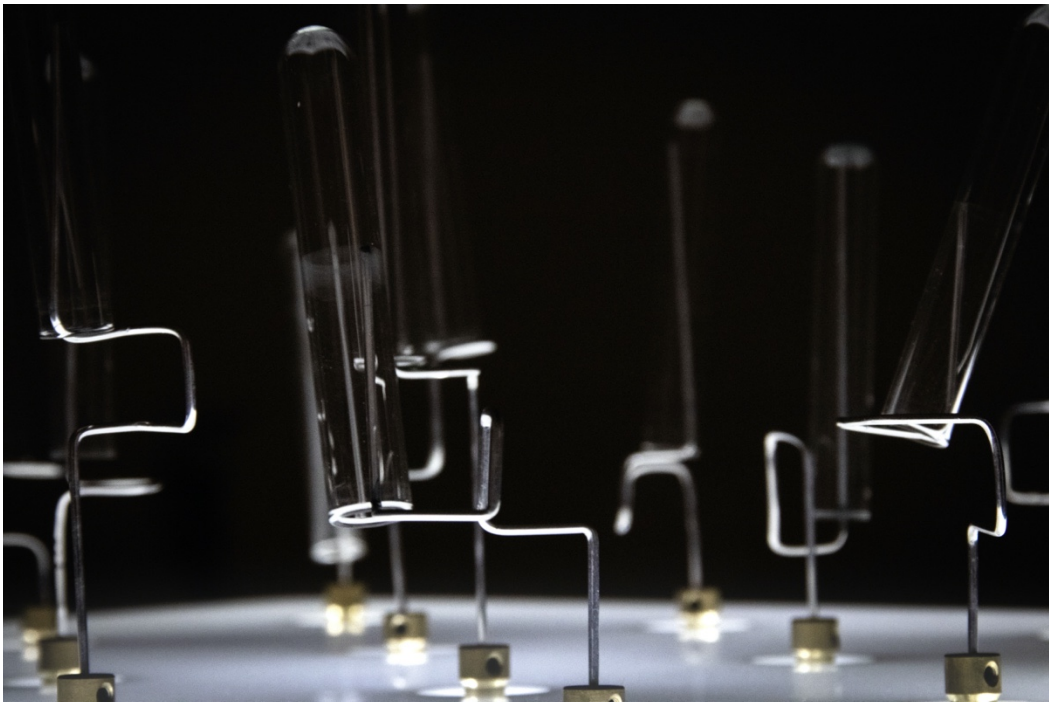

Figure 18 *moment*, Mari Ohno (2017). Photo: Mari Ohno.

[Details]

Title: *moment*

Year: 2017

Materials: test tubes, aluminium, acrylic, motors

Size: W 500 mm × L 500 mm × H 700 mm

moment is motivated by my interest in the inaudible sound of internal rhythms in our bodies. A series of explorations of such internal rhythms of our bodies that I have made since 2011 has been inspired by John Cage's well-known story. It is said that, when Cage entered into an anechoic chamber, he heard two different sounds in the silence of the chamber, which he was told were the sound of his own nervous system and the sound of his bloodstream. This story is written in his book *Silence: Lectures and Writings* (2011).

> Such a room is called an anechoic chamber, its six walls made of special material, a room without echoes. I entered one at Harvard University several years ago and heard two sounds, one high and one low. When I described them to the engineer in charge, he informed me that the high one was my nervous system in operation, the low one my blood in circulation. Until I die there will be sounds. And they will continue following my death. One need not fear about the future of music. (Cage 2011, 8)

In 2011, I visited the NHK Science and Technology Research Laboratories in Tokyo and had an opportunity to enter into an anechoic chamber for the first time. When I was in there, I experienced an unusual hearing of the silence at the beginning, as sounds occurred in a space but were immediately absorbed. Then I became used to being in such an unusually silent space and had an experience similar to Cage's. I heard the two types of unusual sounds: the sound of the fluidic flow beaten by my pulse was sensed 'louder', and the high frequency sound of my nervous system was sensed 'closer' to my ear. While these sounds are actually emitted from our internal bodies all the time, we are not aware of them in our daily lives. It was my strange realisation that many unperceivable events are happening in our bodies in a moment. I was interested in ‘hearing’ this biological sound in a normal acoustic condition in alternative ways.

The beginning of this project is rooted in my studies prior to my PhD, focusing primarily in the field of sound, in my first master’s course at Tokyo University of the Arts from 2011 to 2014. In these three years, I created electroacoustic compositions and sound installations using the inaudible sounds that exist in our lives, by regarding the sounds as clues by which to objectively ‘hear’ the elements of human bodies. My main subject, in connection with these activities, was an artistic expression and use of technology for sounds that exist beneath our auditory thresholds. Even though inaudible sound has been well explored in the arts, I am particularly interested in the human perception and the biological reactions of a human body that are expressed through the medium of sound. I would like to perceive inaudible sounds not as merely sounds but as tools to verify the unperceivable elements of our human bodies. As one of the projects in my master’s study, I explored the sound of the bloodstream through my sound art works to realise the internal sounds of the human body in interaction with our external environment. In this project, I created two major pieces, an electroacoustic composition *floating sound* (2011)[72] and a sound installation *bio effector* (2012),[73] using the sound of the bloodstream as a material for the pieces. These pieces aimed at an extended experience of human hearing, through the transformation from inaudible sounds to perceivable forms other than sounds.

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[72] Mari Ohno *floating sound* (2011), electroacoustic composition, 9 min. 05 sec., performed and exhibited at various venues, including EMPAC New York in 2014, Centro Cultural FIESP Sao Paulo in 2014, and SARC Belfast in 2015.

[73] See pp.12–13 in Chapter 1 for the description and picture of *bio effector* (2012).

floating sound was my first piece using the sound of my bloodstream. The description of the pieces is as follows:

> We release extremely subtle sounds from inside our bodies which are hard to perceive. While the sound is made by the body, it cannot be heard because of the limited audible range that a human being can hear. This work is a composition using the sound of the composer's bloodstream as a sound source. The purpose of this work is to deconstruct and reconstruct the components of personal biological information via computing. These sounds were composed to express another reality beyond the boundary of the animate/inanimate. (Ohno 2011)

While completing *floating sound*, I struggled with the difficulty of expressing inaudible sounds in the format of an electroacoustic composition, which is played through speakers in most cases. Although some unique speakers, such as transducers and parametric speakers, are designed to play beyond the auditory threshold, speakers are normally designed to play sounds within the audible range. For instance, the frequency response of Genelec's 8050B studio monitor is from 32 Hz to 25 kHz (-6 dB) (Genelec, n.d.). An electroacoustic composition using inaudible sound as a material is essentially the outcome of the transformation from inaudible to audible via computation, and this is not purely natural inaudible sound. To overcome this dilemma, I created my next piece *bio effector* within the format of a sound installation that extended the internal sounds of a human body in an environmental way, making it possible to 'sense' the inaudible sound.

As I discussed in my introduction, *bio effector* is a sound installation that vibrates a single membrane suspended in the exhibition space with the sound of the audience's bloodstream sensed in real time; see Chapter 1 *Introduction* for more details and an image of this piece. In *bio effector*, a sort of sound composition can be played through the membrane, whose vibration is controlled by changes in its tension. This piece is an attempt to create a huge instrumental space that coexists with the environment, unlike strings and tympanic instruments. During the exhibition for a month and a half, it was interesting for me to see the variety in the overall appearance of the piece, depending on the audience's physical and psychological conditions. After observing the reactions of the audience and other viewers surrounding the audience in the exhibition space, I thought that it was difficult to make a balance between auditory/visual expressions and interactions in an installation that requires the active participation of the audience. If the piece is experienced as a mere art piece, the audience can engage with it objectively. However, in this piece, the audience realised that the piece is the reflection of their internal bodies. In this situation, the audience paid more attention subjectively, which is closely associated with their physical and psychological conditions. While they are experiencing this environmental instrument, the unperceivable reaction of the audience's internal body is reflected into the piece itself in real time. Thus, these types of interactive installations need to consider not only aesthetic expression and techniques but also the audience's involvement.

In order to handle inaudible sound as a basis of my pieces, I need to transform sound into another perceivable form that is not limited to sound, because it is difficult to experience sound through conventional tools such as musical instruments and speakers, other than as sound. This transformation does not mean using technologies to control the inaudible sounds but the construction of frameworks in which to design the stimulus for sensory perception. The previous two pieces can be described as alternative approaches to how sounds could be expressed in such frameworks.

The sound installation *moment*, as part of this PhD research, demonstrates the emergence of internal rhythms in our bodies, expressed through anthropomorphic[74] objects. The audience can objectively hear the unperceivable sounds that may be happening in our bodies. This piece is an attempt at a co-composition that weaves the unperceivable biological rhythms in our bodies with the perceivable rhythms of artificial sound objects, through a simple mechanical system. The artificial mechanism of the system gains the momentum of the movements derived from the combination of the materials, and physically alters the natural reactions of the movements, like an effector. This piece shows different moments of human pulses in our daily lives as an emergent biological clock from the co-composition of nature and artificial matter.

Process

During the process of working on *moment*, I had a great opportunity to collaborate with Dr Nandi at King's College London. Her research is focused on a new way of observing the original signals of the cardiovascular system by developing a mathematical attractor termed a 'cardiomorph', which re-plots and visualises the raw data in a three-dimensional cube (Nandi and Aston, n.d.). She collects cardiovascular data captured from patients in clinics, such as heart rate, blood pressure and ECG. She analyses and characterises the patterns of these data in patients in order to determine if their health is at risk of deteriorating (Nandi, Venton, and Aston 2018). My conversation with her reminded me of my original feeling in the anechoic chamber, which motivated a series of pieces in this whole project.

[74] See pp.19–20 in Chapter 1 for a description of 'anthropomorphism'.

Our internal bodies are changing with unperceivable events in every moment and releasing inaudible sounds all the time. As a core reflection of our internal bodies, our pulse is changing all the time. The cardiac output changes and responds to many factors of our daily activities at every moment, such as body movement, time, and emotion, as well as health condition. These daily activities include digesting food (eating, drinking), physical exercise (running, walking, standing, sitting), difficult cognitive challenges using brain with mental stress (listening, reading, watching, thinking), and others. These reactions are also different depending on positions within the body, such as heart, brain, liver, kidneys, skin, muscle, and others. For instance, when we eat and drink food, the blood gathers to the stomach to digest it. Thus, the pulse is like a 'fingerprint' of human activities indicating the unperceivable reactions of every position of our internal bodies as a lifelog. I then explored human pulses as unperceivable internal rhythms and planned to create a sound installation drawing an emergent biological clock, inspired by blood as the core unit of our vitalism.

In collaboration with Dr Nandi, I recorded the data of my pulse wave, which combines heart rate and blood pressure, and the amplitude of the waveform over a day using an infrared plethysmograph (ADInstruments)[75] under different conditions doing some daily activities, such as working, listening, walking, sitting, standing, and lying. The waveform signals were processed by specialised software

[75] According to the ADInstruments's website, the infrared plethysmograph (IR Plethysmographs) is described as follows: 'The Plethysmograph is an infrared photoelectric sensor used to record changes in pulsatile blood flow. It operates by recording changes in blood volume as the arterial pulse expands and contracts the microvasculature. The Plethysmograph can be plugged directly into a PowerLab Pod port or any ADInstruments Bridge Amp Front-end (amplifier)' ('IR Plethysmographs'; ADInstruments, n.d.(a)).

(LabChart v8; ADInstruments).[76] This data was collected under instruction from Dr Nandi at King's College London.[77] The following image shows one of the examples of my pulse wave recorded through an infrared plethysmograph (Figure 19).

Figure 19 The waveform of my pulse, on a random day at a random time. In my experiment at Dr Manasi Nandi's laboratory, at King's College London (2017).

A cycle of the waveform of pulse within the aorta is characterised by two peaks with a typical shape. The first higher peak of the pulse wave is caused by the systolic pressure. Shortly after the peak of systolic pressure, a small decrease called a dicrotic notch (or incisura) occurs when the valve of the heart closes. Then there is a second small increase in pressure called a dicrotic wave, before the pressure decreases under the diastolic pressure (Klabunde 2012). In my measurement of my pulse wave by an infrared plethysmograph, the data was recorded from an artery in my finger. The arterial

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[76] The software developed by ADInstruments is available on the following website: https://www.adinstruments.com/support/software ('Software Downloads'; ADInstruments, n.d.(b)).

[77] This data collection did not require ethical approval, as it did not constitute a research experiment. The data was collected from me, by me and used for my own purposes. My data will not be seen or used by anyone else for any research or any other purposes and has been deleted from their system.

pulse pressure was measured by the difference in value between the systolic blood pressure (peak) and the diastolic blood pressure (trough).

This typical waveform of pulse is unique and representative enough to identify the waveform as a pulse. My piece was conceived with the aim of drawing the complexity of the typical waveforms of pulses that include two peaks, influenced by daily activities. With this in mind, I created geometric shapes of motor-controlled objects comprised of wire sticks and glass test tubes, to draw the first peak of the sound artificially beaten by motors with the pre-recorded interval of my pulse, and the second peak naturally beaten by momentum which is caused by the combination of materials of the objects.

This piece consists of sixteen differently shaped objects made of wire sticks and glass test tubes, each mounted on one of the sixteen motors. The motors are controlled by eight microcontrollers to provide power and enable a 360º rotation by the programmed data of the pre-recorded pulse. Triggered by the pulse recorded at different moments, each object moves by alternating clockwise and counter-clockwise and generates sounds by beating the objects. The first movement of the sound objects beaten by pulse derives the second subtle movements beaten by the momentum of the objects. The shape of each object is designed with different dimensions to make different momentums. By repeating a series of movements, the position of the objects is continuously shifting. Although these objects are repeating the same moment of the pulse data, the overall appearance of sonic and visual expression is always different depending on the difference of each pulse and the degrees of rotations. All of the objects stand for an emergent biological clock which represents the intersection of each moment of an internal body and the external activities. For more details, see the 2-5-1. written documentation and 2-5-2.

video documentation in the Appendices, which are in in the folder labelled *2-5. moment* in the folder of *Appendix* 2 on the attached USB memory stick.

Self Evaluation

In terms of projects that position a biological clock within the post-anthropocentric[78] context, some examples by other artists use different approaches to mine. The art space MU in Eindhoven, Netherlands, had an interesting exhibition entitled *Life Time: Biological Clocks of the Universe* from December 2017 to February 2018. This exhibition introduced broader interpretations of time, dealing with various events of the universe, to focus on 'different dimensions and scales of time, from the universal to the personal and from the cellular to the geological, even the astronomical' (MU artspace, n.d.). The pieces in this exhibition illustrate alternative ways of ticking time on unperceivable scales by exploring the intersection of natural and artificial materials.

One representative piece in this exhibition was the kinetic sound installation *Rhythm of Life* (2017) by Thought Collider and Dave Young. Thought Collider is the duo of art, design, and research practice of Mike Thompson and Susana Cámara Leret. The installation gave the audience an opportunity to hear the sound of electro-chemical communications of biophotons emitted from human skin by means of the Photon-Multiplier Tube (PMT). Biophotons are photons of light produced by biological processes which can be observed in plants, animals, and bacteria. The audience could examine the

[78] See pp.18–19 in Chapter 1 for a discussion of my own use of the term 'post-anthropocentric'.

sounds of their own biophotons by placing their hands in the PMT. The activity of the biophotons was transformed into complex rhythms performed in real time through an instrumental system constructed with seven cymbals (Thought Collider, n.d.).

In addition, some artists consider the notion of the time of non-human events beyond human perception in perceptible ways. *Timepieces (Solar System)* by Katie Paterson (2014) takes the format of time with the minimal design of conventional clocks to show the difference of time scales on other planets in the solar system. This piece consists of nine clocks which show calibrated time on Mercury, Venus, the Earth, the Moon, Mars, Jupiter, Saturn, Uranus, and Neptune. The clocks visualise the duration of a day and the length of night, in relation to the other planets (Peterson, n.d.). Another example is the sound installation *Seasynthesis* (2017) by Xandra van der Eijk. This piece creates a soundscape of the North Sea, one of the busiest seas for human activities in the world. It gives the audience an awareness of the influence on the underwater environment through the format of sounds. The ambient noise recorded under the sea contains a vast amount of information, which indicates how humans are affecting the natural environment (Van der Eijk, n.d.).

The exhibition organised by MU explores various notions of time on unperceivable scales through the intersection of nature and artificial matter. As time is a continuous and invulnerable notion, it needs some frameworks in order to sense it in perceptible ways. The biological clock as a core unit of vitalism, pulse, can be defined as an organically and periodically repeated sequence of events which occurs in nature. In the anthropomorphic pint of view, non-living objects which repeat periodic events with certain intervals like pulse can be perceived by us as life-like matter. In this context, the rhythms of biophotons, the rotation and revolution of the planets in the universe, and the waves of the seas, can all be reinterpreted as pulses of nature.

The difference between these pieces and my practice can be shown through the following three characteristics. Firstly, *moment* is a co-composition between pulses naturally occurring within our body and mechanical rhythms artificially made by the kinetic sound system. This piece aims at the interconnection of sonic and visual elements in aesthetic expression, rather than sonification and visualisation. Secondly, my piece extends human hearing to the sounds which occur within an internal body. The sound objects in the piece make it possible to 'listen to' (i.e. perceive) pulses at random moments in a day that are not usually perceived at the time. It implies the diversity and complexity of cardiac events in relation to a body organised by pulse. Finally, the piece has a structure as a piece of music – minimal music. This piece creates a musical structure through the beating of the objects, triggered by the pre-recorded pulse data, as well as the momentum generated by the different object shapes. It also generates a visually different combination of degrees of the objects and it includes irregular elements that can be permanently changed. Therefore, it can bring the audience to a sonic experience with a musical structure that can only be expressed in this piece within the framework of an emergent biological clock.

4. Conclusion

This PhD research engages with sonic and visual anthropomorphism and examines the methodology of co-composition between natural and artificial matter with sonic and visual elements. Seeking a new human perception and cognition of life within the Anthropocene, this thesis utilises life-like behaviours of matter in the compositional process to co-compose sound art works between human and non-human materials. Throughout, this research has unveiled the unexplored potentials of sonic and visual expression created by the life-like behaviours of matter.

One worthwhile approach to authorship and making in the post-anthropocentric context is to connect them with nature, not separate them from it. Natural elements and processes may serve as co-authors in creation and co-makers in production. There is currently a trend for new material techniques that involve nature-driven living systems as co-authors and co-makers, such as protocells, 'biomimicry' (Benyus 2008), and 'material ecology' (Oxman et al. 2015). This indicates both the simple mechanism and the complexity of nature, and the effect of artefacts on the natural world, raising questions about future notions of 'matter'. Nature and artefacts are evolving in more hybrid ways in a coexistent relationship.

In my practice in this PhD research, I have hypothesised that the agency of matter can emerge from its decision making and/or behaviour. To consider the emergent potential of sonic and visual expression with matter, I have investigated life-like behaviours that are found in the generative processes through the organisation of matter. The underlying conceptual framework combines natural elements and processes with my compositional process by analysing and harnessing life-like behaviours, inspired by the concept of ’autopoiesis’ (Maturana and Varela 1980). It comprises three life-like features in the generative processes of materials: 1) fusion and division, 2) network formation, and 3) pulse and rhythm. These life-like behaviours are examined through my practice submitted in the PhD portfolio, which contains works co-composed with autopoietic non-living systems made from genetic materials.

The first contribution of this research is theoretical. In Chapter 2 *Research Context*, I briefly discussed related ideas, extending to interdisciplinary perspectives, within the context of my research practice. It consists of three main topics: 1) the scientific background and philosophical discussions of matter within the Anthropocene, 2) the materiality of sonic experiences, and 3) the genetic algorithms found in recent research and projects in science, art, and design. First, in order to examine the boundary between the natural and the artificial, I investigated the scientific background and social/ethical discussions related to the Anthropocene, and philosophical theories of human/non-human and OOO as described by Bennett, Morton, and others. Then I considered the possible methodology of co-composition between natural and artificial matter. Second, I examined how to interpret sound as matter in order to incorporate the ‘agency’ of matter into co-composition between natural and artificial matter. Specifically, sound can be defined as an acoustic phenomenon whose reception has both temporal and spatial attributes, regardless of audible/inaudible range. Even inaudible sound can be perceived as a sound wave through the vibration of matter. Thus, I considered the materiality of sound by referencing related examples that apply the autonomy of materials in recent design and material engineering. Third, I investigated the scientific history of the chemical evaluation of life, and the recent research trend of protocells, which are comprised of non-living chemicals and have life-imitating properties, to consider the biological properties of life. Then I introduced related projects of protocells and other relevant methodologies in art and design.

This theoretical research aimed to investigate the biological properties of life in order to re-define living matter in the new geological epoch from an interdisciplinary perspective. These explorations addressed how we interpret the ambiguous boundary between natural and artificial matter, and how we analyse and harness it for new purposes, by connecting current theoretical discussions in art, design, science, and philosophy. This theoretical outcome can be applied to propositions of the aesthetic, conceptual, and scientific implications of the intermediate state of matter between nature and artefacts in sound art. In addition, these discussions give some clues to understanding the complex mechanisms and limits of human perception, and the order and disorder of non-human elements. The unperceivable elements and processes of matter can be perceived through the simplification of some important characteristics of matter and their transformation into some other perceptible forms. For instance, recent technologies enable us to create even an intermediate state between living and non-living, by creating artefacts that imitate simplified life-like properties. Artificial life, such as protocells, that is comprised of defined life-imitating properties shows predictable living behaviours. However, this is not a perfect replication of actual living behaviours. Actual living behaviours are more complex, but these simplified life-like behaviours can also create unpredictable and complex results that actual living matter can not. This active quality of matter can be considered as a creative force for sonic and visual expression.

The second contribution of this research is its practical exploration. In Chapter 3 *Practice*, I discussed the experiments and process of my sound art practice. In the early stages of my practice, I conducted the experiments of tissue culture during the residency at SymbioticA; I cultured C2C12 cells and observed their growth process. As a result, I simplified the following three features as life-like behaviours in the organisation of matter, which I explored in my practice.

1. Fusion and division: cell propagation is developed through the generative process of fusion and division.
2. Network formation: cells generate networks to form much larger colonies.
3. Pulse and rhythm: cells show periodic movement like cardiac functions as a core of their life force: pulse (periodic beat) and rhythm (the pattern of sounds).

In order to apply the above three life-like behaviours of matter to sonic and visual expression as a co-author and co-maker in the co-compositional processes, I made five sound installations focusing on each of them. Three pieces, *transition [systemic]* (2017), *transition [characteristic]* (2017), and *moment* (2017), were exhibited at the Science Gallery London and Tokyo Wonder Site (this organisation was re-named 'Tokyo Arts and Space' in October 2017).

The result of my practical exploration has been a series of sound installations that positively incorporate the autonomous reactions of materials as co-author and co-maker, in addition to an artist's intention. These projects aimed to propose new pathways of authorship and making in sound art. My approach highlights the life-like behaviours of matter and demonstrates new methods by which to co-

compose artistic outcomes with life-like autonomous elements and processes driven by other than the artist. Audiences can experience the creativity that comes through co-composition by observing the integrated outcome between the natural and the artificial shown in the pieces. However, what the audience can experience is limited to the human perceptible range. In reality, all matter is made of something that is moving and changing all the time on a microscopic level. The agency of matter may run throughout its 'lifetime', whose scale exceeds human perception. Thus, my practice in this research connotes deeper considerations for the notions of time and space, including extremes from the infinitesimal to the infinite, inspired by 'vibrant matter' (Bennett 2010) and 'hyperobjects' (Morton 2010; Morton 2013). The pieces show matter at a certain moment of change, and the audience can imagine the whole scale of the processes by considering the notion of time and space of the perceived sound.

Throughout both the theoretical and practical explorations in this research, I proposed the methodology of co-composition between natural and artificial matter for new potentials of sonic and visual expression in sound art. By incorporating the autonomous reactions of non-living matter into the compositional processes, an unexpected and surprising creative outcome that humans cannot achieve can emerge. The creative force of non-living matter can be interpreted as the vitalism that matter potentially has. This has an influence on our perception and cognition of the boundary between the living and the non-living, and the natural and the artificial. My practice in this PhD research reflects my aesthetic interest in the boundary between the living and the non-living, within post-anthropocentric considerations of our perception and cognition of the boundary between nature and artefacts in the new geological epoch.

Following my doctoral research, I want to observe and explore other life-like behaviours of non-living materials by applying the same methodology employed here, in addition to other unexplored potentials of the three life-like behaviours that I have explored in this research. The present research targeted the boundary between natural/artificial or life/non-life and conducted practice-based research in the framework of sound art. However, this research has been limited to sonic and visual expressions co-composed within the indoor space of a gallery. As a new approach for further research that suggests the importance of re-examining this premise, it is necessary to discuss the field of land art, or Earthworks, which incorporates a site-specific perspective into artistic expression, either outdoor or indoor.

One of the historical pioneers in land art, Robert Smithson, proposed the idea of 'site' and 'non-site' throughout his art works and writings (Smithson and Flam 1996). Smithson's work is characterised by integrated outcomes between natural and artificial materials, which change all the time according to the environmental conditions within an ecosystem; what he calls a 'site'. Inspired by the concept of 'entropy'[79] in the figurative context, his art works can be classified into two contrasting approaches: a site is a work placed in a specific outdoor location, and a non-site refers to a work that can be placed anywhere, such as in a gallery or museum.

> The site, in a sense, is the physical, raw reality – the earth or the ground that we are really not aware of when we are in an interior room or studio or something like that – and so I decided

[79] According to the *Oxford English Dictionary*, 'entropy' in this context refers to a 'state of or tendency towards disorder; an irreversible dissipation of energy resulting in stagnation or inactivity' (OED Online 2019e).

> that I would set limits in terms of this dialogue (it's a back and forth rhythm that goes between indoors and outdoors), and as a result I went and instead of putting something on the landscape I decided it would be interesting to transfer the land indoors, to the non-site, which is an abstract container. (Smithson and Flam 1996, 178)

For instance, Smithson created a site-specific work entitled *Spiral Jetty* (1970). This artwork is a magnificent counter-clockwise-shaped coil comprised of basalt rocks and earth, located in the Great Salt Lake in Utah (Smithson and Flam 1996). This lake is characterised by a higher salinity than seawater, and the micro bacteria living in the lake dye the water surface a red colour and gradually decompose the work. Due to the rise and fall of the tide, the piece appears only once every few years. Based on his proposition of site and non-site, Smithson's *Spiral Jetty* demonstrates the visual and auditory outcomes that result from the interaction between nature and artefacts.

Smithson's aesthetics inspire me to consider the site-specificity of sonic and visual expression by connecting to current environmental concerns in the post-anthropocentric context. This is because life-like behaviours, including those I have explored through my PhD research, may be changeable depending on environmental conditions, such as sunlight, temperature, and wind. Specifically, I am interested in exploring the possibility of exhibiting sound art works in an environment that merges gallery and ecosystem. By incorporating some elements and processes of site-specific environmental conditions into my sound art works, like Smithson's idea of site/non-site, I may be able to find unexplored potentials of life-like behaviours of matter. However, one of the important issues raised here is that environmental ethics are necessary to consider if I want to get involved in natural environments or ecosystems as a part of my art works. This issue was considered when I conducted my experiments of tissue culture in a lab environment at SymbioticA in the early stages of my PhD practice. Catts and Dr Zurr at SymbioticA, who create and exhibit semi-living objects for their art projects by means of tissues culture techniques in a lab environment, consider the ethical issues in bio art. In Dr Zurr's study, she concludes their ethical framework as follows:

> […] in examining the ethical issues of BioArt it is important first to acknowledge again that BioArt is a pluralist practice, with artists occupying different ethical positions. Some are being used (or happily participate) in the creation of public acceptance for these biotech developments, while others seek to subvert these technologies in order to generate heated public debate about their uses. There are also those who perceive their work to be neutral in this regard, and who opt to use the technologies for purely aesthetic and poetic virtues; or a statement which assumes that aesthetical consideration is an ethics. In practice, the actual art works in general seem in many cases to be much more ambiguous and, once released, in the public domain, they develop their own narrative. (Zurr 2008, 105–106)

After the critical observation of the aforementioned arguments, I reinterpret site-specificity regardless of whether outdoors or indoors as one of the elements for sonic and visual expression and want to explore approaches to artificially establishing the environmental elements and processes within the artwork, not threatening the natural environment or ecosystem. The uniqueness of site-specific environmental elements and processes may lead to the emergence of new interactions with other materials with which to co-compose in more creative ways. My practice in this thesis may also expand with other unexpected sonic and visual aspects through new co-compositional processes between the art works and the environmental conditions. As well as the questions of site-specificity, I would like to explore new parameters of natural materials that can affect the artificial output expressed through time and space beyond human perception and apply these parameters to my co-compositional processes.

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Appendices

Appendix 1: Documentation Materials of the Lab Experiment

All the documentation materials of my lab experiment referred to within this thesis are included on the attached USB memory stick.

1-1. lab experiment

1-1-1. time-lapse recording of C2C12 cells

The time-lapse recording of the growing process of C2C12 cells, in my experiment at SymbioticA, School of Human Sciences, The University of Western Australia. Observed with 200x magnification inverted microscope. Time-lapse recording by Mari Ohno (2016).

1-1-2. time-lapse recording of sea salt crystals

The time-lapse recording of the formation of sea salt crystals, in my experiment at Professor Anatoly Zayats's laboratory, at King's College London. Observed with 20x magnification reflection microscope through a polariser. Time-lapse recording by Mari Ohno (2018).

1-1-3. time-lapse recording of magnesium sulfate crystals

The time-lapse recording of the formation of magnesium sulfate crystals, in my experiment at Professor Anatoly Zayats's laboratory, at King's College London. Observed with 20x magnification reflection microscope through a polariser. Time-lapse recording by Mari Ohno (2018).

Appendix 2: Documentation Materials of the Portfolio

All the documentation materials of my portfolio referred to within this thesis are included on the attached USB memory stick.

2-1. *energy in motion* (2017)
Sound installation for a study in the process of *transition [systemic]*.

2-1-1. written documentation
2-1-2. video documentation

2-2. *transition [systemic]* (2017)
Sound installation exhibited at Tokyo Wonder Site Shibuya in Tokyo, Japan, from 29th July to 17th September 2017, for the exhibition entitled *Shibuyajizai – Infinity, or Self-Territory*. (The organisation was re-named 'Tokyo Arts and Space' in October 2017.)

2-2-1. written documentation

2-3. *transition [characteristic]* (2017)
Sound installation exhibited at Tokyo Wonder Site Shibuya in Tokyo, Japan, from 29th July to 17th September 2017, for the exhibition entitled *Shibuyajizai – Infinity, or Self-Territory*. (The organisation was re-named 'Tokyo Arts and Space' in October 2017.)

2-3-1. written documentation
2-3-2. video documentation

2-4. *spectrum* (2019)
Sound installation for a study in the process of *transition [characteristic]*, in collaboration with Professor Anatoly Zayats at King's College London.

2-4-1. written documentation

2-5. *moment* (2017)

Sound installation exhibited at Science Gallery London in London, UK, 19th–29th October 2017, for the exhibition entitled *Blood: Life Uncut*.

2-5-1. written documentation

2-5-2. video documentation